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A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry

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Prepared for
U.S. Nuclear Regulatory Commission

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A Characterization of Check Valve Degradation and Failure Experience in the Nuclear Power Industry

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Abstract

Check valve operating problems in recent years have resulted in significant operating transients, increased cost and decreased system availability. As a result, additional attention has been given to check valves by utilities (resulting in the formation of the Nuclear Industry Check Valve Group), as well as the U.S. Nuclear Regulatory Commission and the American Society of Mechanical Engineers Operation and Maintenance Committee. All these organizations have the fundamental goal of ensuring reliable operation of check valves.

A key ingredient to an engineering-oriented reliability improvement effort is a thorough understanding of relevant historical experience. A detailed review of historical failure data, available through the Institute of Nuclear Power Operation's Nuclear Plant Reliability Data System, has been conducted. The focus of the review is on check valve failures that have involved significant degradation of the valve internal parts. A variety of parameters are considered, including size, age, system of service, method of failure discovery, the affected valve parts, attributed causes, and corrective actions.

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List of Acronyms

AFW	Auxiliary feedwater
ASME	American Society of Mechanical Engineers
BWR	Boiling water reactor
CCW	Component cooling water
CVCS	Chemical and volume control system
EPRI	Electric Power Research Institute
ESW	Emergency/essential service water
HPCI	High pressure coolant injection
HPCS	High pressure core spray
HPSI	High pressure safety injection
LPCS	Low pressure core spray
NIC	Nuclear Industry Check valve group
NPRDS	Nuclear Plant Reliability Data System
NRC	Nuclear Regulatory Commission
NSSS	Nuclear steam supply system
OM	Operations and Maintenance (Committee of ASME)
ORNL	Oak Ridge National Laboratory
PWR	Pressurized water reactor
RCIC	Reactor core isolation cooling
RCS	Reactor coolant system
RHR	Residual heat removal
WG	Working group

1 Introduction

Oak Ridge National Laboratory (ORNL) has conducted a review of historical check valve failure data under the sponsorship of the Nuclear Regulatory Commission's (NRC's) Nuclear Plant Aging Research Program. The study involves the review and characterization of failure records from the Nuclear Plant Reliability Data System (NPRDS) data base. Failures in which significant internals degradation was detected are being characterized in detail. Parameters that are being considered include the age of the plant when the failure occurred, valve size, manufacturer, system of service, method of discovery, affected valve parts, attributed failure causes, and corrective actions.

1.1 Background

The American Society of Mechanical Engineers (ASME) Committee on Operation and Maintenance (OM) of Nuclear Power Plants has established a Working Group on Performance Testing of Check Valves in Light Water Reactor Power Plants (OM-22), which is chartered with developing check valve performance test requirements. The Working Group (WG) met for the first time in June 1990.

Early on, the OM-22 membership recognized that a thorough understanding of historical failure patterns was critical to several aspects of the code development activities being pursued. A literature search by the WG found that while some historical failure data studies had been completed and documented, the studies were normally not oriented toward providing the kinds of information needed in code development activities.

One study that was initially selected by the WG as a basis for consideration in the development of disassembly and examination requirements (note that these requirements would apply only to valves that could not be properly tested) was a paper presented by M. L. Scott at the EPRI Power Plant Valves Symposium II. [1] Scott reviewed NPRDS failure records for events occurring during the years 1985-1987. Moderate seat leakage and external leakage events were then eliminated from the data. Failure rate vs. valve size, valve service time, and plant system were discussed. One of the conclusions drawn by Scott was that there was a tendency for a large number of failures relatively soon after installation, followed by a period of fewer failures during the 4- to 9-year service period, and then subsequently followed by a sharp increase in failure occurrences. The sharp increase was attributed to wear-out of the check valves.

As OM-22 deliberated on the establishment of appropriate disassembly and examination intervals, the conclusion in the Scott study regarding the sharp increase in failures beginning at about 9 years was noted. The WG used this study as the basis for formulating requirements for 8-year disassembly and examination limitations for those valves that could not be properly tested.

During the WG's consideration of the paper and its application to code development, some questions arose concerning the technical validity of the WG's basis. As a result, ORNL was asked to conduct a preliminary review of failure data. This review was conducted by non-qualitatively tabulating NPRDS reported failures and valve populations during the years 1985–1987 (the years of the Scott study) as well as the years 1984–1990.

The preliminary review indicated that the age-related aspects of the study appear to have been heavily influenced by the age of plants in operation during the years considered. Figures 1.1 and 1.2 illustrate the basis for this observation.

Figure 1.1 provides comparative plots of the number of valves in service during the period of the study and the failure data from the WG basis study. The similarity of the traces indicates that the failures-vs-age trend noted in the study is strongly affected by the valve population in existence during the study period.

Figure 1.2 shows comparisons of all check valve failures (regardless of failure nature) and population during the same period. It provides further indication of the importance of the valve population to overall valve failure rate.

To provide a preliminary indication of the non-population-influenced valve failure-age relationship, normalized plots of the WG basis study and all check valve failures during the 1985–1987 period are provided in Figure 1.3. There do not appear to be strong, conclusive trends from the data shown, based on preliminary review.

The results of the preliminary review substantiated concerns about the use of the WG's basis study conclusions for further use in code development activities. The NRC's Nuclear Plant Aging Research Program asked ORNL to conduct a more thorough assessment of the historical failure data. This report documents the results of the study.

ORNL–DWG 93–7283

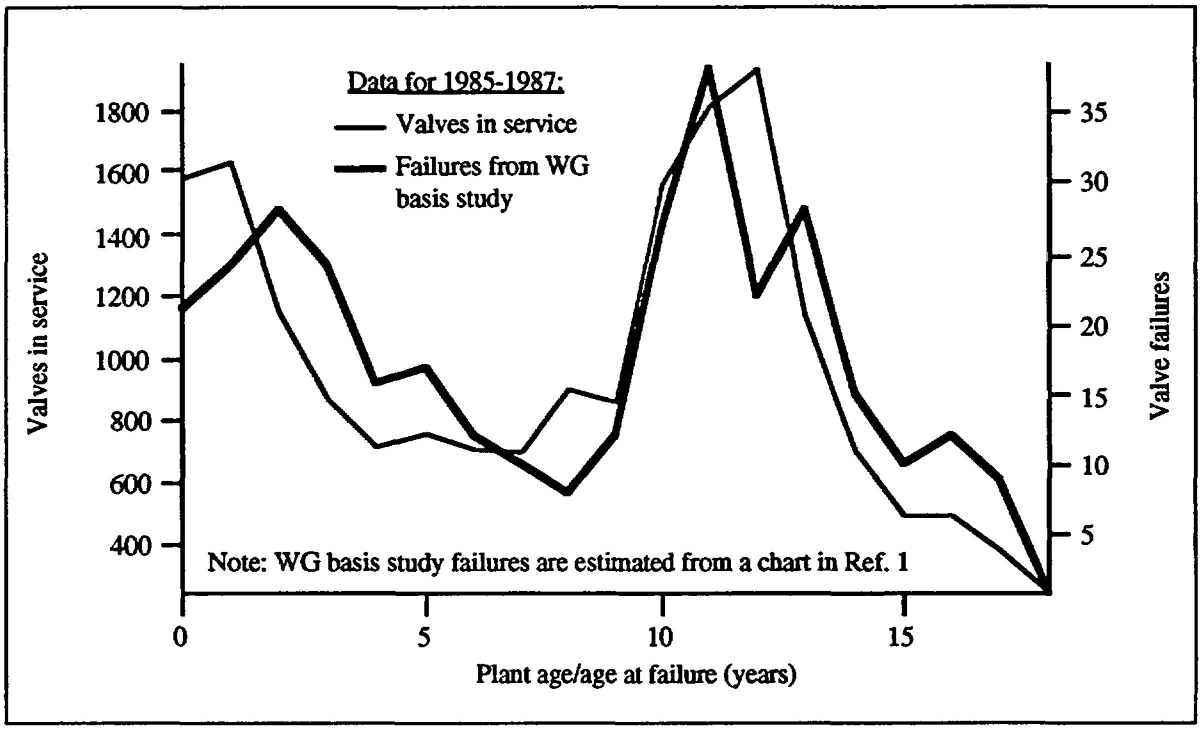

Figure 1.1 Comparison of failures vs age at failure (WG basis paper) and valves in service vs plant age

ORNL–DWG 93–7284

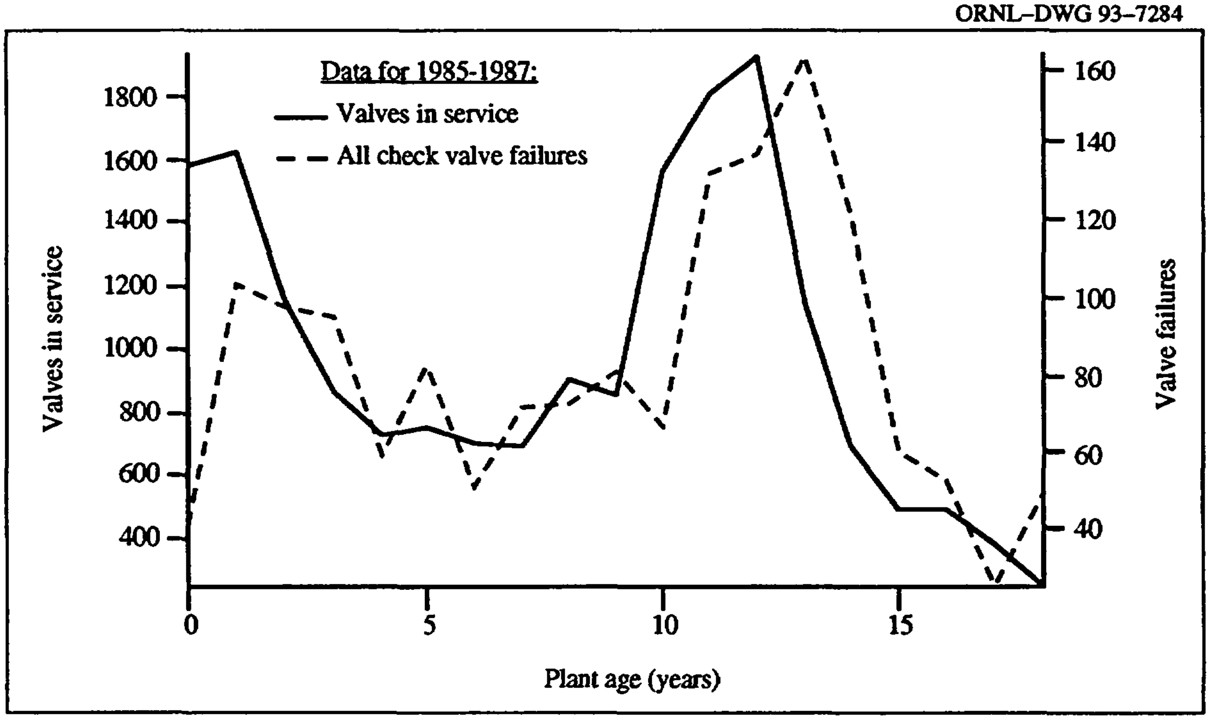

Figure 1.2 Comparison of all check valve failures and valves in service

ORNL-DWG 93-7285

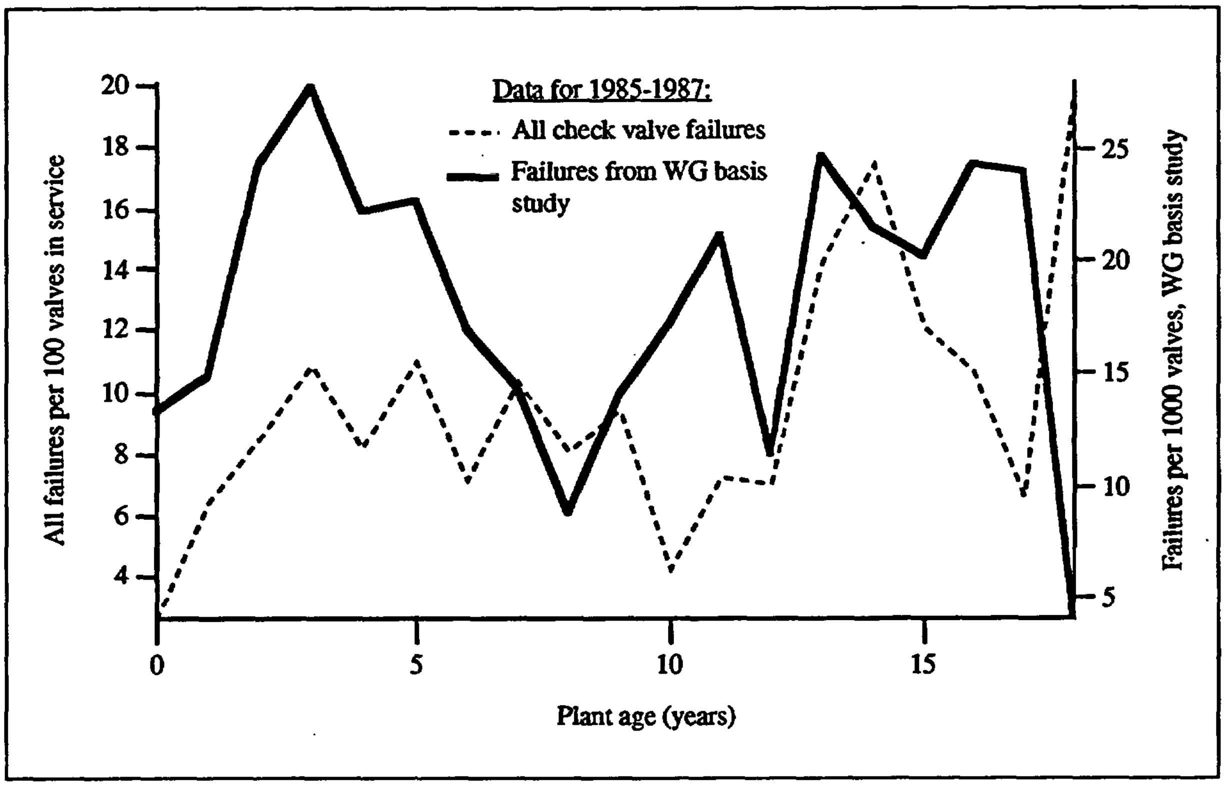

Figure 1.3 Comparison of normalized failure data

2 Study Methodology

2.1 Scope

A primary goal of this study is to identify any apparent correlations of valve failure rates with plant age, valve size, system of service, manufacturer, and other characterizations that are not inherent in the NPRDS data base, such as the affected valve parts, the method of failure detection, and extent of degradation.

Narratives and other pertinent information, such as manufacturer, system of service, and component service and failure dates, were initially downloaded for all check valve failures, yielding an initial data base with 4680 failure records. This data base contained all failures that had occurred through the end of 1990 and entered into NPRDS as of May 28, 1992. The data were then filtered to eliminate failures that did not involve internals degradation (for example, external leakage at the valve bonnet gasket) or for which only very minor seat leakage existed.

After eliminating the nonsignificant failures, it was decided to only consider failures that occurred between 1984 and 1990, inclusively. Failure reporting to NPRDS improved dramatically beginning in 1984, and it appeared that use of prior years' data would not reflect the reporting practices employed thereafter. Failure events occurring in 1991 and afterward were not considered because at the time the data was downloaded, all failure reports for 1991 were not filed. Future updates to this study will address failures occurring in 1991 and subsequent years.

After this filtering process that eliminated insignificant failures and failures occurring outside the study period 1984-1990 was completed, a data base containing 1227 failure records remained, or about 33% of the overall failures occurring during the period (3761 failures). This compares with our estimate of slightly over 20% of all failures deemed to have been significant by Scott.[1]

Of the 1227 failures, 1081 (or 88%) affected valves listed in NPRDS as safety-related. Failures of valves in the feedwater, condensate, and diesel systems were responsible for half of the remainder (which included valves classed as non-safety related and other). Because of the relatively small group that were not designated as safety-related, as well as the fact that many of those so classified are typically either included in the IST or other plant check valve programs, all valves were included in further review. It should also be noted that 88% of the population of check valves currently included in the NPRDS system are classified as safety-related. In summary, results achieved from a study of all NPRDS data should not be significantly influenced by the small non-safety related portion of the population.

Vacuum breakers are included in the NPRDS check valve data, which is appropriate, since most vacuum breakers *are* check valves in a physical design sense. This study includes those vacuum breakers which are reported as check valves in the NPRDS data.

2.2 Limitations in the Filtering Methodology and Inherent Structure of the Data Base

Some failures records have minimal information about the nature of the failure, noting only that certain parts were replaced. It should also be noted that some of the eliminated failures may have technically made certain valves inoperable. For example, minor seat leakage may have been discovered during a containment isolation valve leak test that technically made the valve inoperable. Alternatively, significant external leakage may render certain valves inoperable.

The primary area of interest in this study is the assessment of check valve failures that involve significant wear or other degradation of valve *internal* parts. In the cases where the only valve problem is external leakage or minor internal leakage that results in failure of the valve to meet administrative leaktightness limitations, the problems could reasonably be expected to be routinely detected by current means (i.e., visual observation of external leakage and seat leakage measurement testing).

As noted above, one of the intents of the initial filtering was to eliminate those failures that only involved minor internal leakage. Because the narratives do not clearly define the extent of leakage in most cases, it was not practical to apply hard criteria to this aspect of the filtering process. As a result, there are almost certainly some failures that were retained for further evaluation that are no more significant than some that were eliminated. On the other hand, because of the extensive number of failure narratives that were initially reviewed, it is likely that some failures that should have been retained were filtered out.

It must also be recognized that reporting practices vary from plant to plant, as well as with time and individuals at the same plant. This feature also makes the data base not particularly useful from an absolute failure rate standpoint.

Another factor that certainly affects the results of this review is the growing level of utility attention to check valve problems in recent years. This is exemplified by the formation of the Nuclear Industry Check (NIC) Valve group, which has sponsored a series of test of non-intrusive monitoring techniques. Further, the NIC group is in the process of developing various documents to assist utilities in optimizing maintenance and test programs for check valves. Two likely results of the significant increase in attention to check valve concerns have been an enhanced awareness of problem valves and a reduction in the threshold for what qualifies as a failure.

In this context, it is important to point out that the term "failure," as applied throughout this report is a generic term and does not mean, in many cases, that the valve was totally incapable of performing its required functions. Generally speaking, the "failures" only involve a degradation of one or more valve functions.

One of the parameters considered in the characterization process was age. Both plant age at failure and the age of the component were considered. These ages were derived as follows:

Plant age = Time from initial criticality to failure start date

Component age = Time from component inservice date to failure start date

There is minimal uncertainty associated with plant age; however, the component age calculated per the above can be misleading. Specifically, it does not reflect the replacement of parts (or even the entire valve, if replaced with an identical valve) when either preventive or corrective maintenance is performed. Thus, the component age at failure is not a perfect representation of time to failure.

In close relation to the component age limitation, repeat failures were not analyzed, primarily due to time limitations. The results of repeat failures analysis could provide valuable information, and should be considered for future studies.

Another feature that was not explicitly considered was design failures that were corrected early in life. It is almost certain that some design problems are identified fairly early in plant life and corrected by either using a different valve design, changing system operation, or other action. This area may also be worth exploring further in future studies or by others.

Failure of a valve that has generic implications (either industry-wide or for a particular plant) often results in inspections performed expressly to determine if the same failure mechanism has affected other valves. For instance, if a valve which was identical to 10 other valves at a particular plant were found with a missing lock wire, it is likely that the other valves would be inspected. Thus, several failures may be detected in a relatively short period of time. This pattern was noted in some cases, but not specifically evaluated.

In light of the limitations noted above (and others), the use of the filtered data to determine absolute failure rates is not only not feasible, but any such use would be misleading.

Note also that several utilities reviewed the ORNL characterizations of the failure data. ORNL discussed individual failure narratives with two utilities. These reviews and discussions reinforced the limitations associated with lack of familiarity with plant specific design and, in some cases, either a misinterpretation of the narrative or the inadequacy of information in the narratives upon which to adequately complete the characterization. However, even with these limitations in mind, it is believed that the results presented herein provide at least general indicators of importance of the various characterization parameters, particularly those that are inherent in the NPRDS data base, such as valve size, age, and system of service (because interpretative errors and biases are not a factor for these parameters).

The fact that the data cannot be used for absolute failure rate determination does not, however, inherently limit the usefulness of a failure review process, if it is recognized that the data must be considered in a relative sense rather than an absolute sense. This approach was used in this study, and will be discussed in more detail below.

2.3 The Characterization Process

Several of the characterization parameters of interest are inherent in the NPRDS data base. Those parameters chosen for consideration in this study, which are specifically inherent in the NPRDS data, include:

- System
- NSSS
- Valve size
- Manufacturer
- Component age
- Plant age

In addition to considering these inherent parameters, several additional parameters were developed during the failure data review. These parameters include:

- Failure mode
- Extent of degradation
- General detection method
- Specific detection method
- System normal operating status
- Failure area or source

Brief discussions of each of these additional parameters follow.

2.3.1 Failure Mode

Failure modes were classified in seven categories. Brief descriptions of each and the *general* characterizations of the extent of degradation for the failure mode are given in Table 2.1.

2.3.2 Extent of Degradation

Extent of degradation is not a judgment about the significance of the effect of the valve degradation/failure upon the system or plant, from either a safety significance or availability standpoint. Rather, it is intended to be an indicator of how seriously degraded the particular <u>valve</u>

Table 2.1 Failure modes descriptions and normal classification

Failure mode	Abbreviated name used in charts	Description	Extent of degradation[a]
Corrosion, general wear, foreign material and/or misalignment resulting in improper seating and excessive leakage	Improper seating	This category includes all failures in which the valve failed to properly seat (excluding the stuck open and restricted motion cases), whether due to seat erosion or corrosion, lack of full seat/disk contact, or unknown causes of reverse flow leakage. The leak rates vary - from those that were relatively minor to those that were substantial in nature. As a result, these type failures were generally categorized as *Moderate* in severity. In reality, the extent of degradation varied from light to significant. A few of these failures were categorized as *Significant*, but only if the circumstances surrounding the failure so dictated (such as some other piece of equipment failing to perform as required due to the failure).	*Moderate*
Disk/other part off or broken	Disk/other part off or broken	Either the disk to other internal part has come loose from the assembly or a valve internal part was found to be cracked or broken.	*Significant*
Free or loose (not detached) or impact/friction damaged part	Loose/damaged part	Some portion of the assembly, generally in the hinge pin or disk stud area, was found to be loose or otherwise not in a proper assembly condition (with no other attendant problems, such as stuck open, etc.). Examples are: • A valve with anti-rotation lugs was free to rotate due to improper installation. • Seat ring was loose or improperly positioned • Substantial hinge pin or disk stud wear • Hinge arm/backstop impact damage	*Moderate*
Restricted motion or reduced flow	Restricted motion/flow	Free motion of the valve is restricted. In some cases, this resulted in reduced flow through the valve.	*Significant*
Stuck closed	Stuck closed	Valve will not open when forward pressure is applied.	*Significant*
Stuck open	Stuck open	Includes valves in which the disk is clearly stuck open or cocked, including, for example, cases where foreign material prevented the valve from fully closing or the disk cocked in the seat due to wear of the disk stud. Note that there are some cases where the reverse flow rate is extremely high (such as where a pump is rotating backwards that are in the "Corrosion, general wear..." category because the narratives did not explicitly state the valve was stuck open, cocked, etc.). However, the extent of degradation would be the same (*Significant*).	*Significant*
Miscellaneous failure	Miscellaneous	A failure which did not fit any of the above categories.	*Moderate*

[a] The normal characterization for the various failure modes is shown. A very limited number of failures were accorded the other rating.

was. As is indicated in the table, the failure modes *Stuck open, Stuck closed, Restricted Motion or Reduced Flow,* and *Disk/other part off or broken* were generally classified as *Significant*, while failure modes *Corrosion, general wear, foreign material and/or misalignment resulting in improper seating and excessive leakage, Free Or Loose (not Detached) or Impact/Friction Damaged Part*, and *Miscellaneous* were generally classified as *Moderate*. The *Moderate* classification takes in quite a bit of territory, and includes failures which, no doubt, were relatively innocuous, as well as failures that were quite serious. With this classification means, a stuck open valve in a critical high pressure safety-injection system application would be classified as the same significance as a stuck open valve in a balance of plant, non-safety-related system. Again, the classification of significance is *not* significance to plant operation, but rather a judgment of the extent of valve degradation.

Two examples of the implementation of this approach are as follows:

Case 1

A 12" reactor coolant system pressure boundary isolation valve was found to leak just in excess of the technical specification limit (normally 5 gpm for this size valve). The plant was shut down to repair the soft valve seat.

Case 2

A non-safety related service water pump discharge check valve stuck open. There was no impact on the plant, in terms of technical specification action statement entry, forced shutdown for repair, etc.

For Case 1, the failure was categorized as *Moderate*, while for Case 2, the failure was deemed *Significant*.

While the results of this type of analysis are therefore inherently not geared toward system or plant effect, they are useful in a component sense. Any attempt to quantify system or plant effect would of necessity require not only much more detailed knowledge on a plant specific basis, but would mandate considerations that were not appropriate in this study, such as failure modes and effect analyses and probabilistic modeling. It is recommended that additional consideration along this line be given for future study.

2.3.3 General Detection Method

The first detection method approach was more general, dividing the failures into those discovered by programmatic monitoring and those discovered by other means. By programmatic monitoring it is meant that some scheduled test or maintenance procedure, e.g., leak test, inservice testing, scheduled disassembly and examination, etc., was the means by which the failure was detected. Non-programmatic detections include such events as routine observations by operators or observation of abnormal equipment operation that alerted the presence of a check valve problem. Table 2.2 lists and briefly describes the general detection means.

2.3.4 Specific Detection Method

The second detection method approach deals more specifically with the method of detection used, regardless of whether the problem was detected as part of a planned test or not. Table 2.3 lists and briefly describes the specific detection means. It should be noted that certain specific detection methods are not independent of the general detection method. For example, leak tests are normally used during surveillance or in-service tests.

Table 2.2 General detection method

General detection method	Description
Programmatic	Observed during the conduct of a surveillance test, in-service inspection or test, leak rate test, or periodic preventive maintenance(test, scheduled inspection, etc.).
Routine observation	Observed off-normal plant instrumentation, such as level/pressure, etc., during the course of normal operation. Includes such observations as elevated AFW pipe temperature by feeling of piping.
Abnormal equipment operation	Observed off-normal operation of plant equipment, such as reverse rotation of a pump, frequent cycling of a compressor, or lifting of a relief valve.
Special inspection	Found degraded condition during an inspection performed due to failure of a similar valve at either the plant in question or some other plant (such as an inspection performed as a result of an NRC Notice on some particular manufacturer's valve), or as a part of an inspection process that was not routine in nature.
Miscellaneous or unclear	Did not fit any of the above categories. Includes failures found as a result of correcting other valve problems (such as finding a disk/seat clearance problem when replacing a leaking gasket). Also included those failures for which the general detection means were not defined.

Table 2.3 Specific detection methods

Specific detection method	Description
Disassembly and/or inspection	Degradation/failure discovered when the valve was disassembled and examined or a special inspection was performed; includes both inspections conducted as a part of a programmatic disassembly and examination effort, plus inspections performed for other reasons.
Other maintenance	Degradation found when conducting maintenance on another component, or when correcting an unrelated check valve problem (such as replacing a leaking bonnet gasket).
Nonhydraulic indication	Observation of some indication, such as unusual noise or difficulty in operation of a stop check valve or failure of a power operated valve to stroke, that the valve was not functioning properly.
Leak test	Degradation/failure found during the conduct of a local leak-rate or other leak-type test.
Nonintrusive test	Degradation/failure found by use of nonintrusive means (primarily radiography).
Not specific	The specific indicator was not included in the narrative; either no indication or a generic indication such as "... an operator noticed that the valve was not seating...".
Hydraulic indication	Operator or other person noticed abnormal hydraulic indication, such as higher than normal pressure, level, or temperature upstream of a valve that should be closed.
Pump/comp. rotation	Operator observed a pump or compressor rotating in reverse.

2.3.5 System Usage

The normal system operating status or usage was also ascribed. This characterization indicates whether the system is (1) normally operating, (2) infrequently operating (in support of startup and/or shutdown), or (3) used in automatic demand or testing situations only. Table 2.4 indicates the assignment of the various plant systems to their operating status; PWR and BWR systems are combined where system general functions are common.

2.3.6 Failure Area or Source

The failure area or source was identified to designate what portion of the valve was affected; alternatively, if the problem was due to the presence of foreign material, it was so identified. The failure areas and abbreviated names used in charts are provided in Table 2.5.

Table 2.4 Operating status of plant systems

System	Normal status	System	Normal status
AFW	Shutdown support	Feedwater	Normally operating
CCW	Normally operating	HPCI	Standby
Combustible gas control	Standby	HPCS	Standby
Condensate	Normally operating	HPSI	Standby
Containment fan cooling	Normally operating	LPCS	Standby
Containment isolation	Normally operating	Main steam	Normally operating
Containment spray	Standby	RCIC	Standby
Control rod drive	Normally operating	RCS	Normally operating
CVCS	Normally operating	Reactor recirculation	Normally operating
Diesel cooling water	Normally operating	RHR	Shutdown support
Diesel fuel oil	Standby	Standby gas treatment	Standby
Diesel lube oil	Normally operating	Standby liquid control	Standby
Diesel starting air	Standby	Suppression pool support	Standby
ESW	Normally operating		

Table 2.5 Description of failure areas

Failure area/source	Description
Hinge pin	Degradation or failure in the hinge pin or the portion of the hanger arm that interfaces with the hinge pin, including bushings
Disk stud/hinge arm	Degradation or failure of the disk stud or of the portion of the hanger arm that interfaces with the disk stud, including nuts, washers, and antirotation lugs; also includes the backstop area
Seat	Degradation or failure of the disk in the area where it interfaces with the seat, the seat itself, and/or disk/guide areas
Penetration	Degradation of a body penetration, such as packing or a stem which interferes with proper valve functioning
General wear	Applied to cases where there was wear of a general nature and specific affected areas were not identified
Foreign material	Degradation in which the presence of foreign material caused the valve to not function properly. Foreign material is clearly not an "area"; its presence can cause degradation of any of the above listed valve parts.
Unknown/other	Self explanatory

2.3.7 The Normalization Process

As discussed previously, questions previously arose concerning the technical validity of the WG's basis. Because the data showed, for example, that the number of failures vs age was heavily influenced by the population of valves in service over the time period considered (Figures 1.1 and 1.2), a normalization process is used herein to account for both population sizes and service life of the valves. Generally speaking, the process involves dividing the number of failures for a given category within a field (e.g., valves ≤2 in. in size) by the number of valve-years of service for that category of valves during the years 1984 to 1990. The number of valve-years of service is determined by looking at the period of service of each individual valve in the time period and summing the totals for all valves in a particular category. For example, if a particular valve was placed in service in 1982 and remained in service through 1990, it would have accumulated a total of 7 valve-years of service during the 1984-1990 (inclusive) period. Alternatively, if the valve was placed in service in 1987, it would have accumulated 4 valve-years of service.

The first step in the normalization process is to determine the overall failure rate for all valves. This is determined by dividing the total number of failures characterized (1227) by the total number of valve-years (123,204). The result, 0.00996, is the normalizing value that is applied to the individual category failure rates to determine the "Relative Failure Rate." As an example, there were 338 failures of valves ≤ 2 in. in size. There are 47,852 valve-years experience for this category. The failure rate for this category of valves is calculated to be

$$\frac{338}{47852} = 0.00706.$$

The relative failure rate for ≤ 2-in. valves is then calculated to be:

$$\frac{0.00706}{0.00996} = 0.71.$$

Because of a considerable number of factors, not the least of which is the variability in plant reporting practices in NPRDS, it is deemed inappropriate to report absolute failure rates. Furthermore, the numeric results generated in this study are not intended to represent absolute reliability factors, so to address these concerns, most results are presented as relative failure rates.

By normalizing, a good indication of how a particular category (e.g., ≤ 2-in. valves) within a field compares with other categories in the field is developed; a relative failure rate of unity indicates that the particular category's failure rate is equal to the failure rate of the population as a whole. In the above example, ≤ 2-in. valves fail at a rate roughly 71% of the rate at which the population as a whole fails. The normalizing process used in this study thus accounts for variables such as population size or service life, which have been shown to influence the number of failures, as well as to allow easy comparison across a field with numbers that are less likely to be misinterpreted or misapplied.

Some cross-correlations of parameters did not lend themselves to the normalization process described above. For example, when cross-correlating failure mode and affected area or detection method, the valve-year methodology clearly does not apply. For such cases, the normalization method is applied to yield an indication of the relative importance within one of the characterizations. This type of normalization process might be used to show, for example, the relative likelihood of a failure in the hinge pin area to cause improper seating in comparison to failures in all areas combined.

3 Analysis Results

As discussed in Chap. 2, both inherent and ascribed characterizations of the failure data were considered. This chapter will present the results of the tabulation of the data. Most information will be presented in a normalized fashion, based on the normalization process described in Chap. 2. In some cases, the normalization process could not be used; in such cases, the results will be reported in another fashion. In a few other cases, the normalization process applied uses a lower level normalizing factor instead of the overall failure rate; in these cases, the specific process will be described.

The results of the characterizations were developed not only for the variety of the individual parameters, but in a cross-correlation fashion as well. The cross-correlations provided unique insights that could not be seen at the top level. However, when a variety of parameters are cross-correlated, each against the other, the size of data to be considered grows exponentially with each layer of review. To avoid excessive involvement in all aspects of the cross-correlated data, this chapter will address only the top-level results and some of the more interesting cross-correlation results. There are certainly notable features that will not be discussed. For reference purposes, a more complete set of top level and cross-correlated results are provided in the appendix as full-page charts. It is also suggested that the reader refer to the appendix for more detail as well as somewhat expanded views.

Table 3.1 provides figure numbers applicable to the individual characterizations and cross-correlations. Both the appendix and this chapter's figure numbers are shown, where applicable. It should also be noted that because the perceptibility of trends can depend upon the means of presenting cross-correlated data, many cross-correlations are presented in two formats in the appendix. For example, if one were interested in finding the charts that display the results of the cross-correlation of age and size, Table 3.1 indicates that Figures A.1.3 and A.2.2 of the appendix are applicable, as is Figure 3.14.

It should be noted that the specific valve type (e.g., conventional swing check, lift check, etc.) may have a significant influence on failure rate for certain applications. Unfortunately, the NPRDS database does not specify the specific valve type, thereby precluding study of this effect.

3.1 Component and Plant Age

Figure 3.1 presents the results of the characterization of relative failure rate by the age group of the valve. As can be seen, there is a moderate increase from the first 5 years to subsequent age groups; however, the trend is not particularly strong. Note that valves over 20 years in age are not shown due to the limited service experience of valves in this age group.

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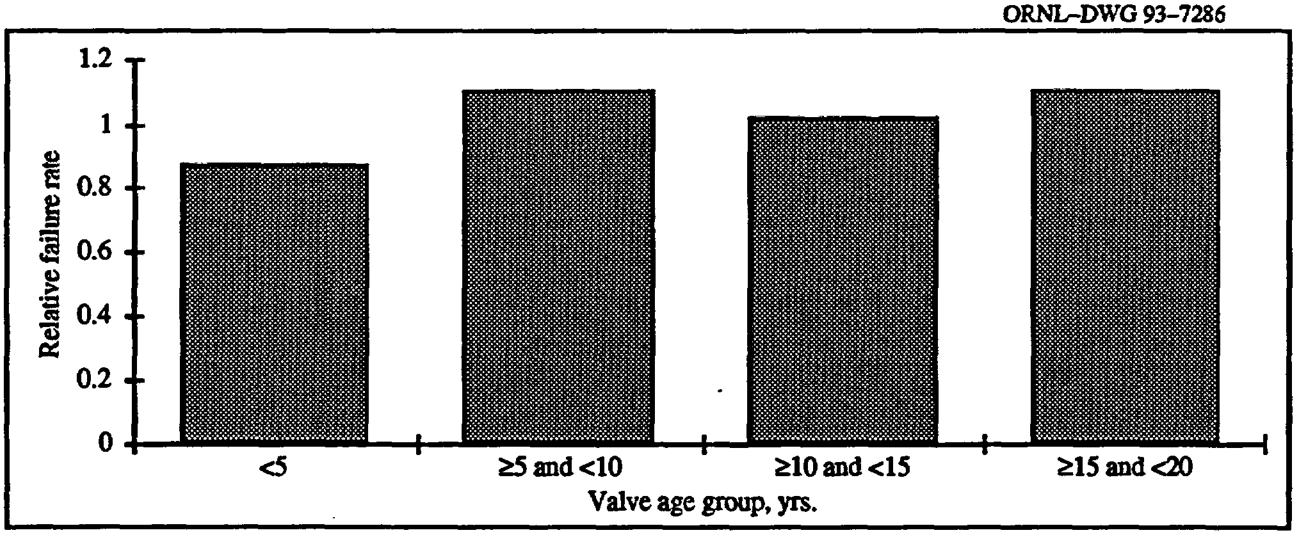

Figure 3.1 Relative failure rate by component age group

Figure 3.2 shows the relative failure rate vs. the *plant* age group. A somewhat more observable trend is seen that appears to be linear with plant age. The exact reason for the different appearances of Figures 3.1 and 3.2 is not clear. One possibility is that valve applications that have been severe enough to warrant valve replacement (and thus put the valve application into a younger category) have also resulted in failures of the changed design. This possible explanation was not verified. Clearly, the failure rate–age relationship is not strong, regardless of whether considering plant age or component age. However, the trend seen with plant age merits monitoring.

Table 3.1 Characterization method charts

	Age	Size	System	Manuf-acturer	NSSS	System usage	Failure mode	Affected area	General detection method	Specific detection method	Discovery process	Extent of degradation
Age	3.1, 3.2, A.1.1, A.1.2	3.14, A.1.3	3.15, A.1.4	A.1.5	A.1.6	3.16, A.1.7	3.17, A.1.8	3.18, A.1.9	A.1.10	A.1.11	3.19, A.1.12	3.20, 3.21, 3.22, 3.23, A.1.13
Size	A.2.2	3.3, A.2.1	A.2.3	A.2.4	A.2.5	3.24, A.2.6	3.25, A.2.7	3.26, A.2.8	A.2.9	A.2.10	3.27, A.2.11	3.28, A.2.12
System	A.3.2	A.3.3	3.4, A.3.1	3.29, 3.30 A.3.4	A.3.5	N/A	3.31, A.3.6	3.32, A.3.7	A.3.8	3.33, A.3.9	3.34, A.3.10	3.35, A.3.11
Manufacturer	A.4.2	3.36, A.4.3	A.4.4	3.5, A.4.1	A.4.5	A.4.6	A.4.7	A.4.8	N/A	N/A	N/A	A.4.9
NSSS	A.5.2	A.5.3	A.5.4	A.5.5	3.6, A.5.1	A.5.6	A.5.7	3.37, A.5.8	A.5.9	A.5.10	A.5.11	A.5.12
System usage	A.6.2	A.6.3	N/A	A.6.4	A.6.5	3.7, A.6.1	3.38, A.6.6	A.6.7	A.6.8	A.6.9	A.6.10	3.39, A.6.11
Failure Mode	A.7.2	A.7.3	A.7.4	A.7.5	A.7.6	A.7.7	3.8, A.7.1	A.7.8	3.40, A.7.9	A.7.10	A.7.11	A.7.12
Affected area	A.8.2	A.8.3	A.8.4	A.8.5	A.8.6	A.8.7	A.8.8	3.9, A.8.1	A.8.9	A.8.10	3.41, A.8.11	3.42, A.8.12
General detection method	A.9.2	A.9.3	A.9.4	N/A	A.9.5	A.9.6	A.9.7	A.9.8	3.10, A.9.1	N/A	N/A	3.43, A.9.9
Specific detection method	A.10.2	A.10.3	A.10.4	N/A	A.10.5	A.10.6	A.10.7	A.10.8	N/A	3.11, A.10.1	A.10.9	3.44, A.10.10
Discovery process	A.11.2	A.11.3	A.11.4	N/A	3.45, A.11.5	3.46, A.11.6	A.11.7	A.11.8	N/A	N/A	3.12, A.11.1	A.11.9
Extent of degradation	N/A	3.49, A.12.2	3.47, A.12.3, A.12.4	A.12.5	A.12.6	A.12.7	N/A	A.12.8	3.48, A.12.9	A.12.10	N/A	3.13, A.12.1

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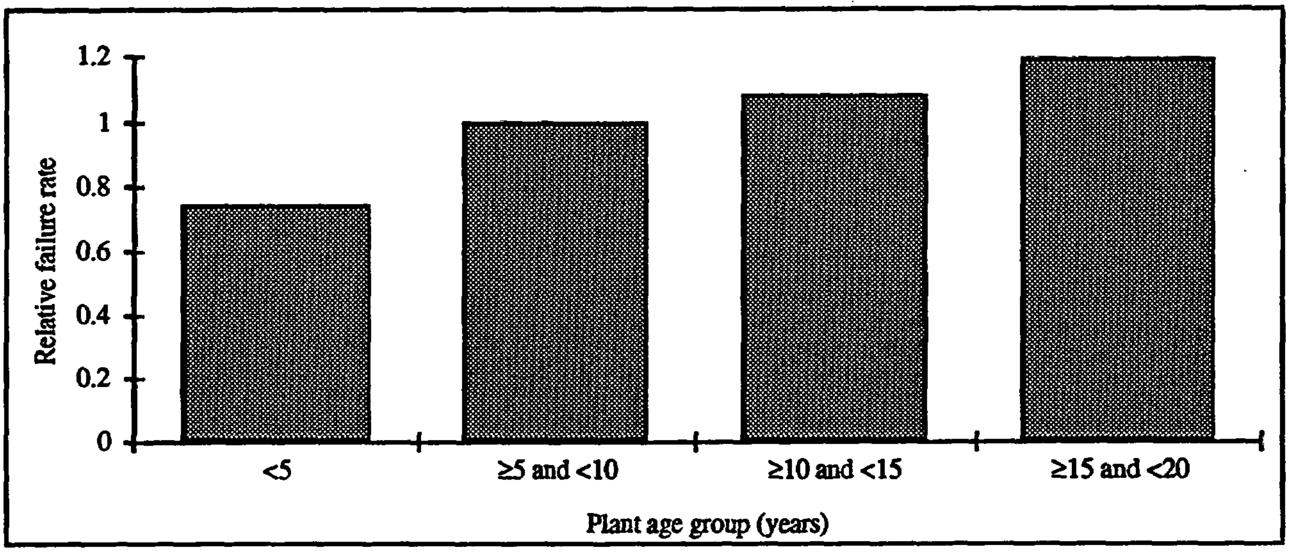

Figure 3.2 Relative failure rate by plant age group

3.2 Valve Size

Figure 3.3 provides both the relative failure rate and the population distribution as a function of valve size groups. There is a very clear correlation between failure rate and valve size, inasmuch as the valves that are > 10 in. nominal size experienced a failure rate that was about double that for the smaller size groups. Another important feature is that there are almost twice as many very small (≤ 2 in.) check valves in service as the other three group sizes selected. One could logically conclude that the highest rate of return for improvements in monitoring and preventive and predictive maintenance would clearly be in the largest valves.

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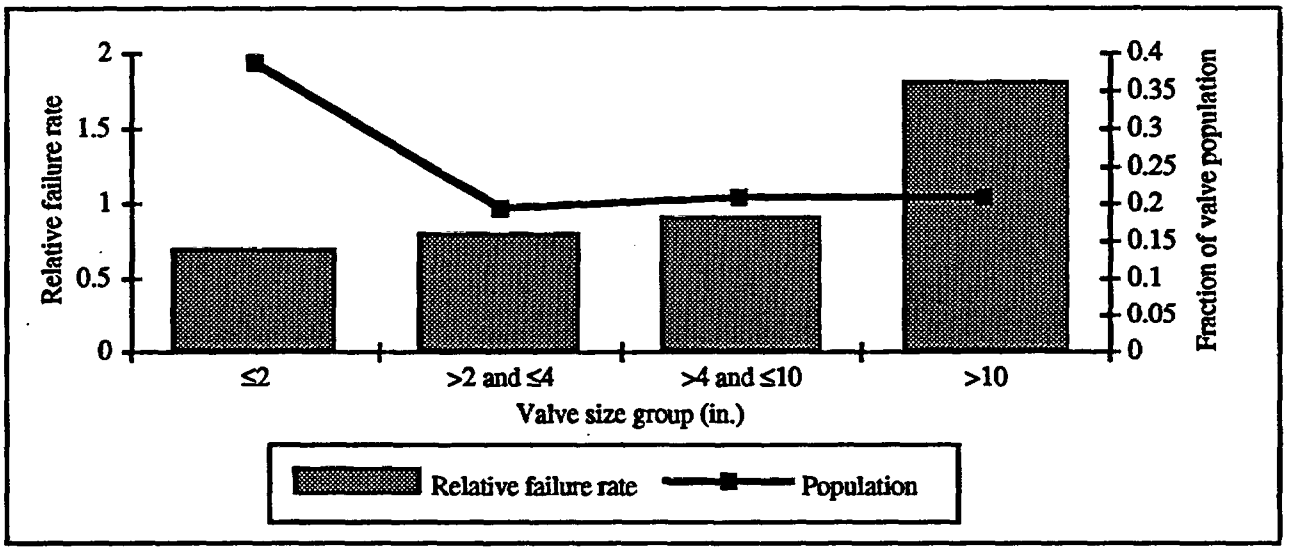

Figure 3.3 Relative failure rate and population by size group

3.3 System

Figure 3.4 indicates the relative failure rate by system of service, ordered from highest to lowest. Only systems with more than 1000 valve-years of service were included. Four systems — emergency or essential service water (ESW), feedwater, diesel starting air, and main steam — had significantly higher relative failure rates than did the other systems. The relative failure rate for ESW was more than 2.6 times that for all systems. Note that three of these four systems (ESW, feedwater, and main steam) are normally in service, have a significant number of relatively large valves, and contain either high energy fluid or raw water. The fourth, diesel starting air, is significantly different in that it contains only relatively small valves, is not normally operating (assuming the check valves hold receiver pressure to keep the compressors from cycling), and handles air.

3.4 Manufacturers

Figure 3.5 shows the relative failure rates and population distribution for manufacturers with more than 1000 valve-years of accrued service during the study period. While certain manufacturers have a significantly higher failure rate than others, the conclusion that valves made by these manufacturers are inherently failure prone would certainly be inaccurate. It was noted that some manufacturers' valves tend to be used in applications that are particularly severe, and as a result, have a significantly higher failure rate. The results shown in this chart should be considered in the light of other information, and not as stand-alone conclusive evidence. Some of the non-design related reasons why some manufacturers have much higher than average failure rates will be discussed in section 3.13.4, which deals with cross-correlations between manufacturer and other parameters.

3.5 Nuclear Steam System Supplier (NSSS)

Figure 3.6 indicates the relative failure rate and population distribution by NSSS. Interestingly, boiling water reactor (BWR) plants showed a slightly higher relative failure rate than did the three pressurized water reactor (PWR) plant types, which had almost identical relative failure rates. As discussed earlier under the section on manufacturers, other factors must be considered. One particularly pertinent factor is that, generally speaking, BWR plants have more valves that are included in the in-service test programs than at PWRs, and a greater number of valves are leak tested. As a result, failures that would not otherwise have been detected are more likely to be manifested, resulting in an apparently higher failure rate. Section 3.13.5 will discuss this in more detail.

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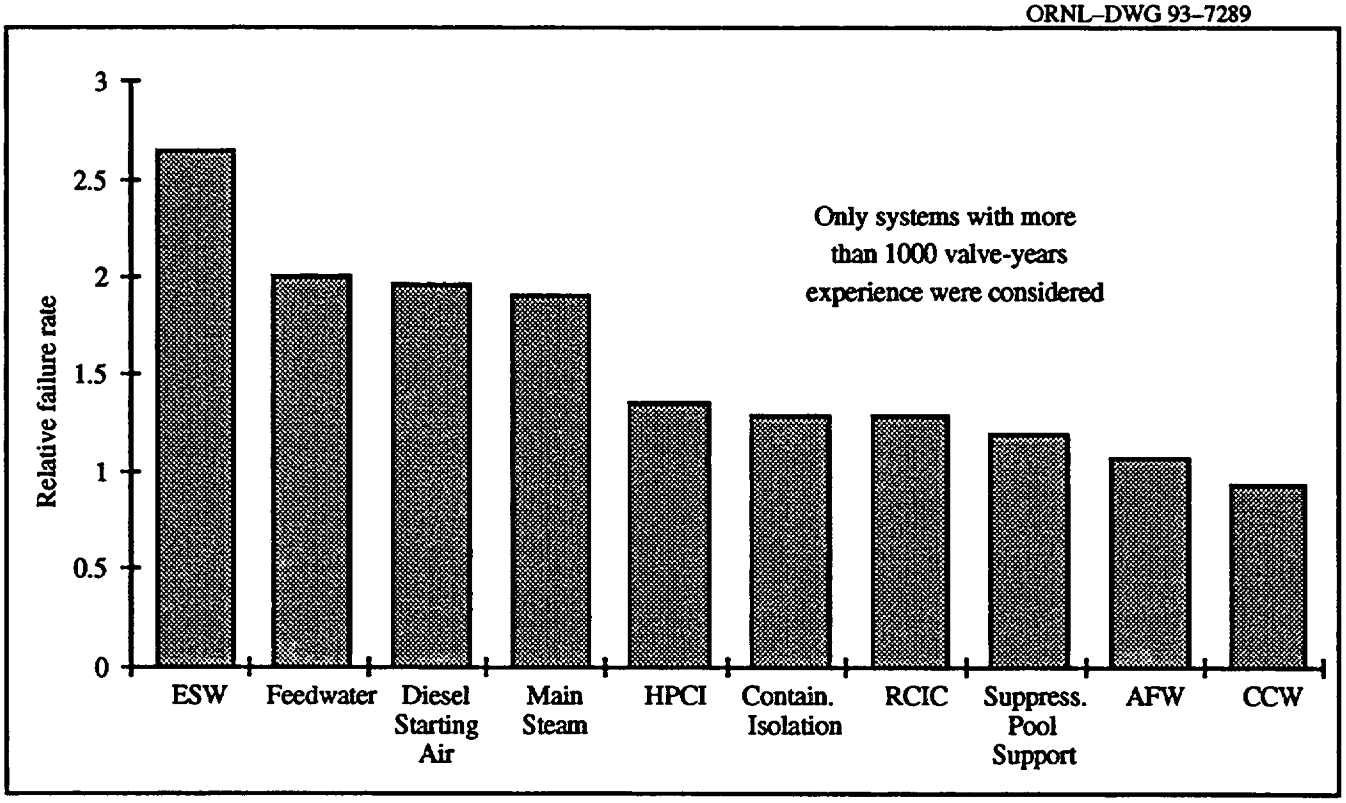

Figure 3.4 Relative failure rate by system for the ten systems with the highest overall failure rate

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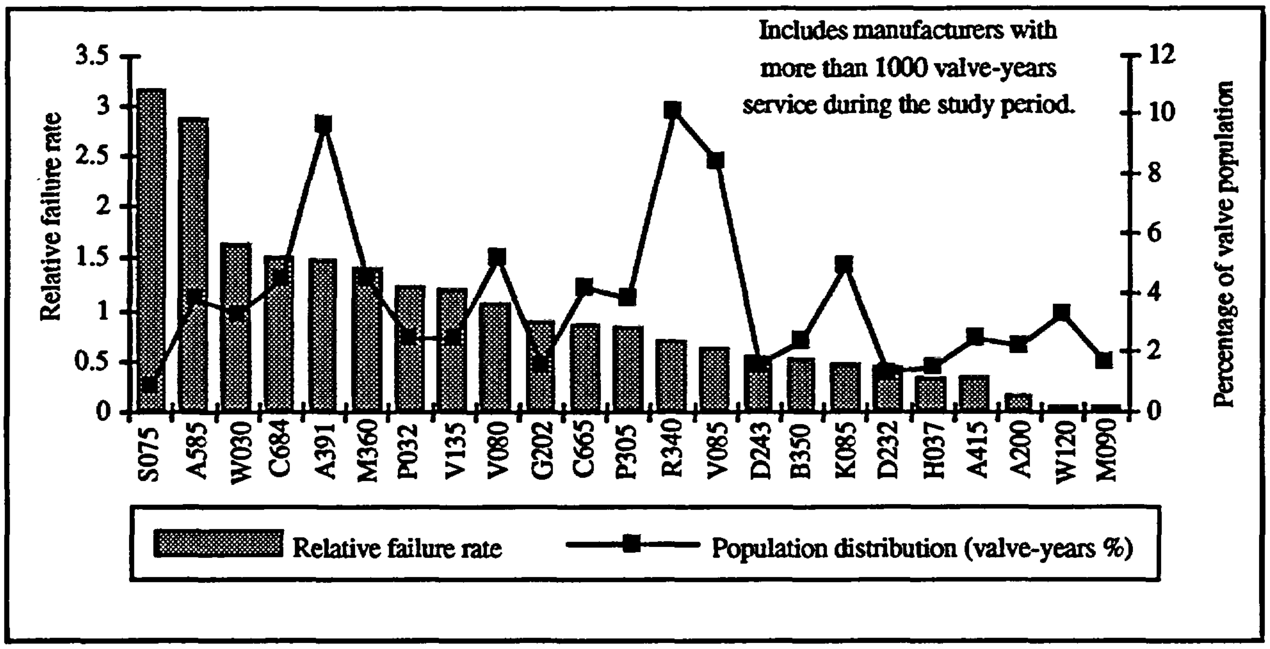

Figure 3.5 Relative failure rate and population distribution by manufacturer

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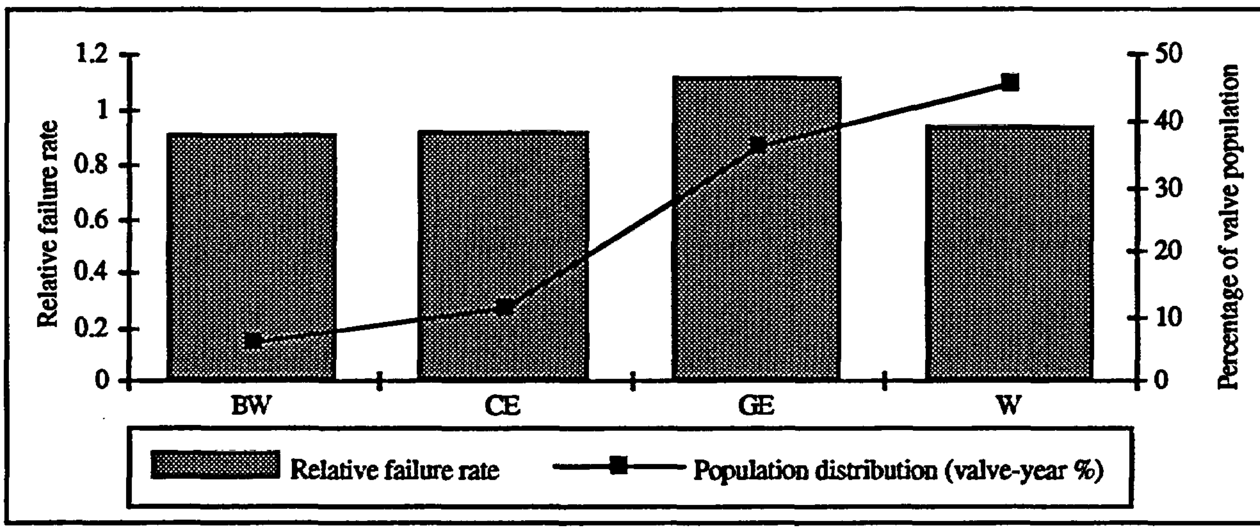

Figure 3.6 Relative failure rate and population distribution by NSSS

3.6 Normal System Usage

The normal system usage is an important factor in the service life of check valves. Three classes of system usage were identified for this study:

- normally operating,
- used in support of shutdown operations, but not during normal operation, and
- essentially used only in testing or in response to transient/emergency conditions.

The designation of normal system usage for both BWR and PWR systems is provided in Table 2.4.

Figure 3.7 indicates relative failure rate by normal system usage. While normally operating systems do have a clearly higher relative failure rate than shutdown/testing type systems, it is not dramatically higher, as might have been expected, and is certainly not representative of the service hours seen under flow conditions.

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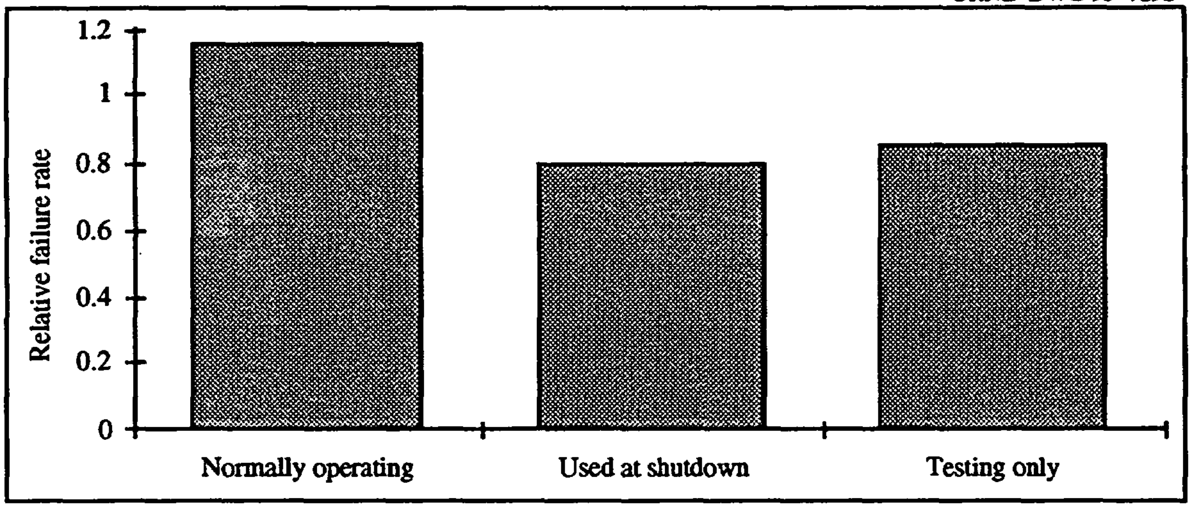

Figure 3.7 Relative failure rate by system usage

3.7 Failure Mode

Figure 3.8 provides the distribution of failures by failure mode. This is not based on relative failure rates; rather, it provides a picture of the extent to which each failure mode was prevalent in the population of failures characterized. Clearly, *Improper seating* was the most likely failure mode. The term *Improper Seating* is an abbreviated term which refers to the failure mode included in Table 2.1 as *Corrosion, general wear, foreign material and/or misalignment resulting in improper seating and excessive leakage*. Many of the failures that fell into this category were difficult to characterize in terms of extent of degradation, failure area, etc. The second largest failure mode was *Stuck open*, which comprised 28% of all failures. *Disk/other part off or broken* accounted for 10% of the failures, while *Restricted flow/motion* and *Stuck closed* conditions were responsible for 7% each.

Perhaps the most surprising result was the number of *Stuck closed* valves. Stuck closed valves were found in several systems and applications. For example, stuck closed valves were found in 18 different systems. The main steam, diesel starting air, and ESW systems had the most stuck closed cases. System chemistry conditions varied and included treated water (e.g., condensate, feedwater, and CCW), untreated water (ESW), air (diesel starting air), and steam (main steam). To the extent possible, the specific application involved was identified. The two most common applications affected were pump/compressor discharge check valves and vacuum breakers. It should be noted that most of the cases in which vacuum breakers stuck shut were found during testing which measured the required force/pressure to open. For these valve applications, relatively tight restrictions are applied for opening pressure. All four valve size groups were affected, but over half of the stuck closed failures were in the smallest size group (≤2 in.).

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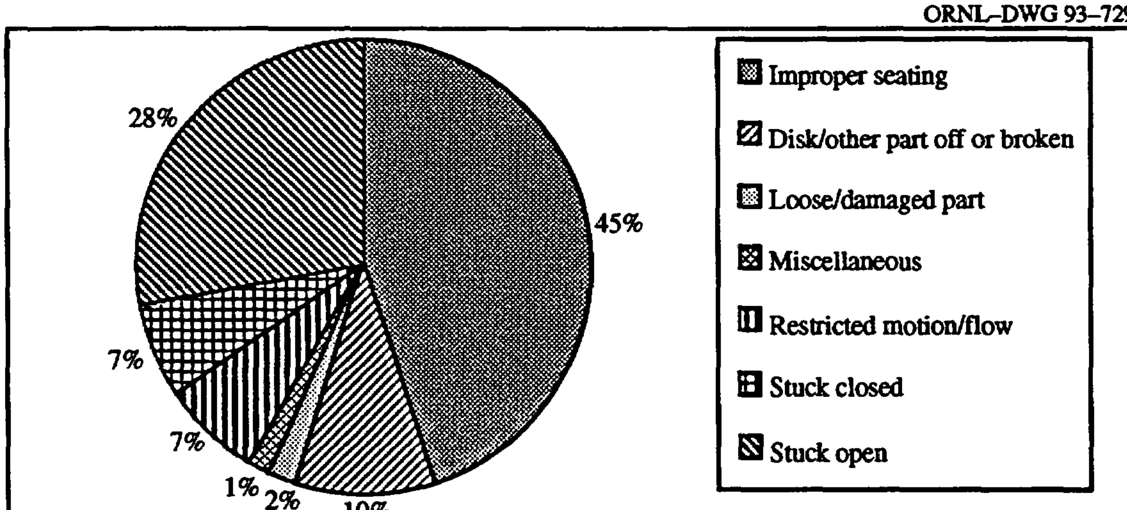

Figure 3.8 Distribution of failures by failure modes

3.8 Failure Area

Figure 3.9 indicates the distribution of failures by failure area. The sum of the fraction exceeds one because some failures affected multiple areas. As expected, the seat area and general wear, followed by hinge pin area degradation, were the leading sources, and were followed by disk stud/hinge arm and foreign material. The area labeled as *Penetration* applies to failures related to a movable valve body penetration (such as the valve stem for stop check valves).

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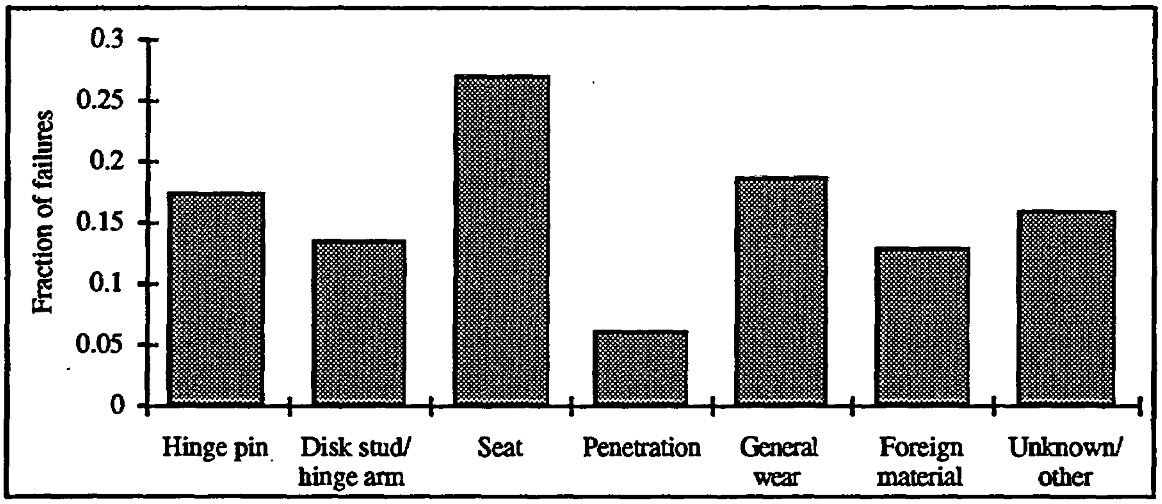

Figure 3.9 Distribution of failures by failure area or source

3.9 General Detection Method

Figure 3.10 shows the distribution of failures by the general method of detection. Slightly over half of all failures were detected by programmatic means, such as local leak rate testing or in-service testing. Nineteen percent of the failures were detected by the observation of abnormal equipment operation (such as a pump rotating in reverse).

3.10 Specific Detection Method

Figure 3.11 provides the distribution (no normalization) of failures by the specific detection method. About one-third of the failures were detected by what is termed *Nonspecific*, which means that the exact way in which the valve degradation / failure was manifested was not described in sufficient detail to place it in one of the other categories. The next largest group of failures was detected by *Leak test*, followed by *Disassembly and/or inspection, Hydraulic indication, and Nonhydraulic indication.* Only about 2% of the failures were detected by use of *Nonintrusive tests*; all but one of the failures detected under the *Nonintrusive test* category were found by radiography; the remaining failure was detected acoustically (in late 1990). It should be remembered that during the majority of the period covered by this study, several currently used non-intrusive techniques were not available.

Note that there is not always a direct connection between a specific discovery method and the general discovery method. For instance, hydraulic indication (pressure, flow, level, or temperature) could be observed during the general discovery process of programmatic monitoring, routine observation, abnormal equipment operation, etc. On the other hand, all leak tests (a specific discovery method) would be considered to fall within the general discovery method category of *Programmatic*.

3.11 Discovery Process

Figure 3.12 indicates that about 54% of the failures were detected programmatically (note that this corresponds specifically to the programmatically detected failures identified under the general discovery method section above. The remainder of the general discovery method categories are combined under the title of *Nonprogrammatic* for this level of consideration.

3.12 Extent of Degradation

A top level indication of the distribution of failures by the extent of degradation is shown in Figure 3.13, which indicates that the failures considered in this review were approximately equally split between the somewhat arbitrary categories of *Moderate* and *Significant*.

ORNL-DWG 93-7295

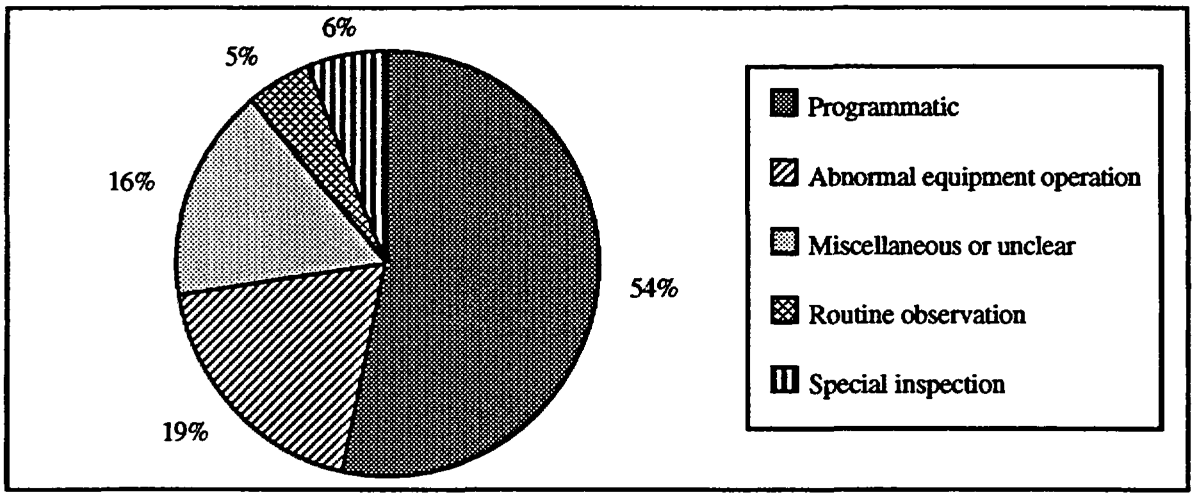

Figure 3.10 Distribution of failures by general detection method

ORNL-DWG 93-7296

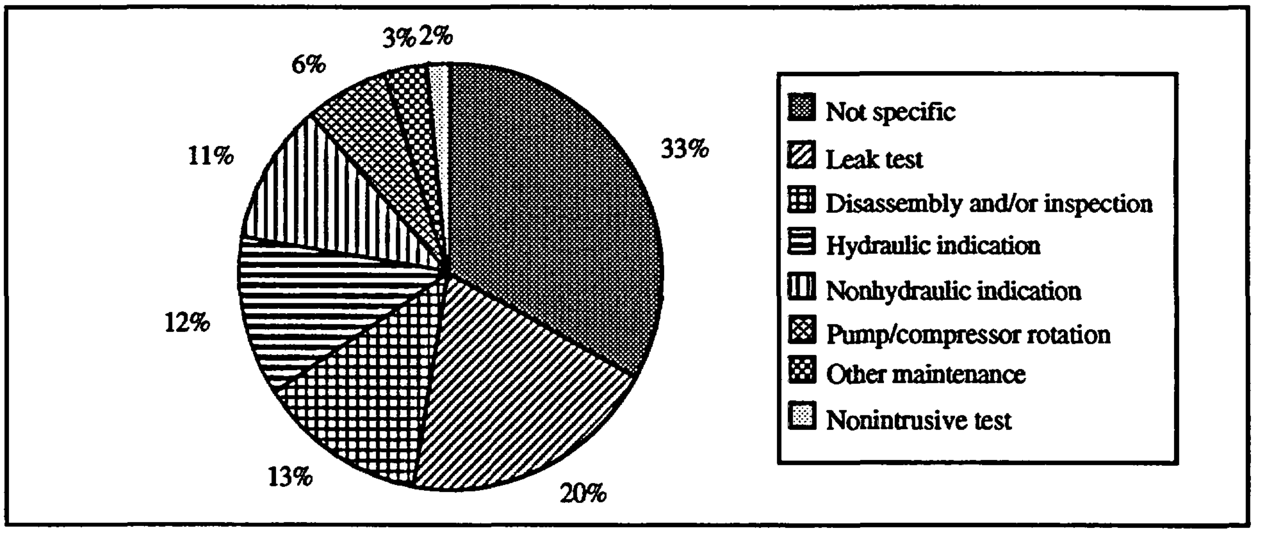

Figure 3.11 Distribution of failures by specific detection method

ORNL-DWG 93-7297

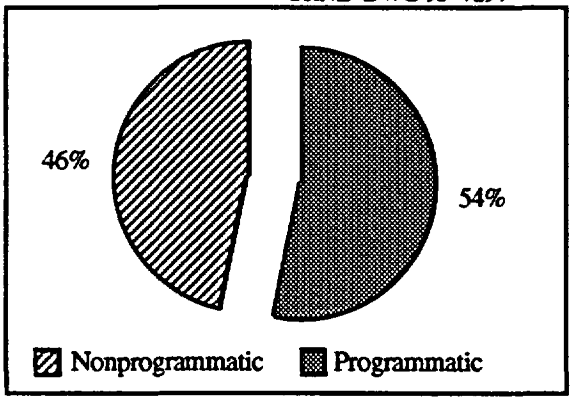

Figure 3.12 Distribution of failures by general discovery process

ORNL-DWG 93-7298

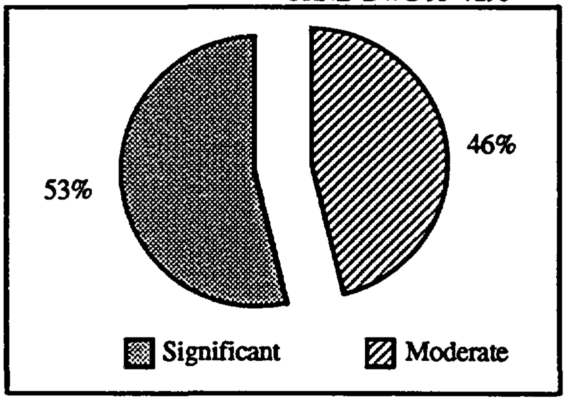

Figure 3.13 Distribution of failures by extent of degradation

As discussed in Chap. 2, the extent of degradation characterization is not intended as a judgment of the effect on the system or plant, but rather an estimate of overall valve degradation. Its sole purpose is to help identify, inasmuch as possible, false positive indicators. A good example of the usefulness of this characterization will be presented in the discussion on system vs other parameter cross-correlation results (Section 3.13.3), where the extent of degradation by system provides a useful indication of relative system experience.

3.13 Cross-Correlation Results

Cross-correlations of all of the above discussed characterization methods were made to gain insights into dominant effects. The appendix shows the results of all cross-correlations, from the perspectives of both parameters. Due to the extensive nature of the appendix, only a few of the results are presented below, and from only one parameter's perspective. Refer to the appendix for additional cross-correlations, as well as different structures for presenting the results of each cross-correlation.

3.13.1 Valve Age Group Cross-Correlations

Figure 3.14 shows the result of the cross-correlation of valve age and size groups. While there are no dramatic trends, the fact that the larger valves are most failure prone is seen in all age groups. Interestingly, as the component age increases, the relative failure rate of the smallest valves increases in comparison to the larger valve sizes. For instance, in the first 5 years, the relative failure rate of >10-in. valves is about three times that for ≤2-in. valves. However, in the 15 to 20 year time frame, the ratio is less than 2.

Figure 3.15 provides the results of the cross-correlation of valve age and system for the four systems with the highest overall relative failure rates. Note that the distribution changes significantly from the younger to older component age groups. For instance, although ESW has a high relative failure rate for all valve age groups, it does not uniformly increase with valve age, while feedwater valves show a continually increasing failure rate with component age and, in fact, have a higher relative failure rate than ESW valves in the ≥15- and <20-year age group.

ORNL-DWG 93-7299

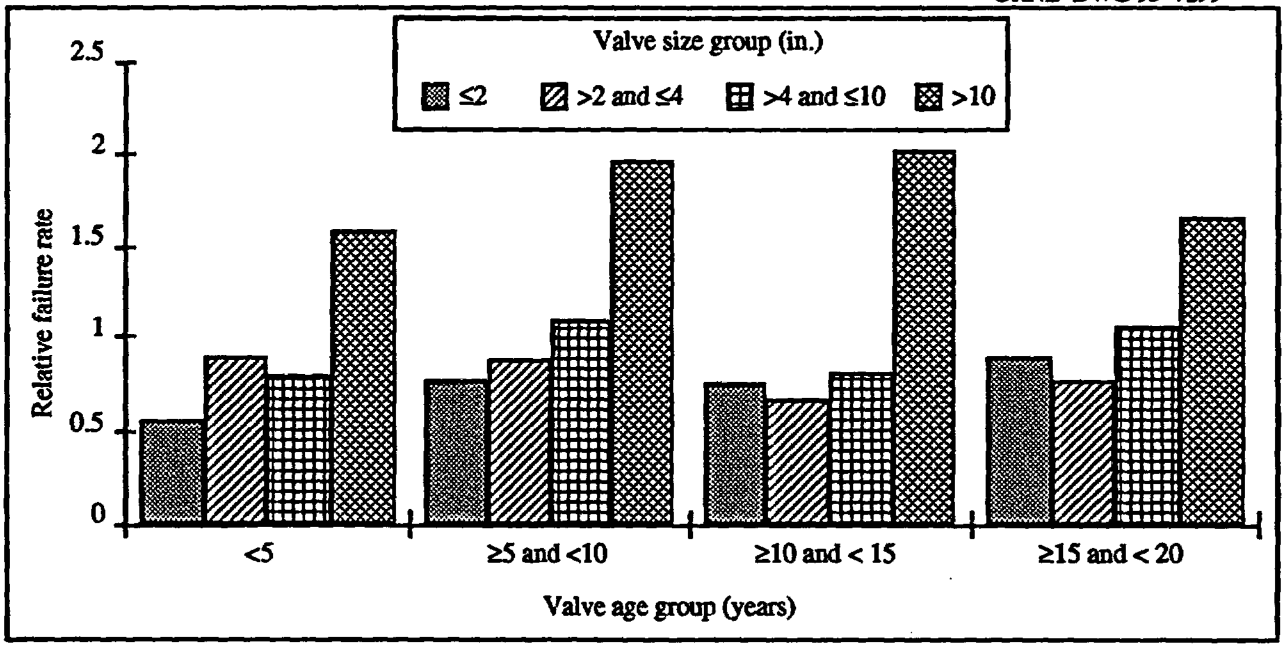

Figure 3.14 Cross-correlation of valve age and size groups

ORNL-DWG 93-7300

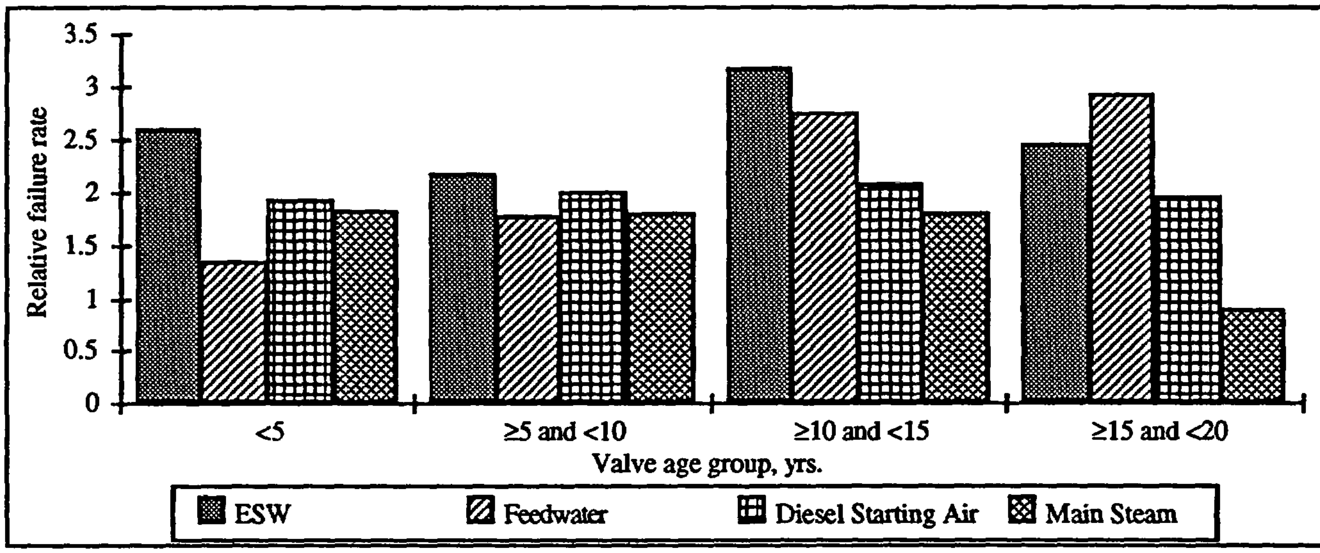

Figure 3.15 Cross-correlation of valve age group and system for four systems with the highest overall failure rate.

Figure 3.16 shows the results of the cross-correlation of valve age group and system usage. This chart indicates that the relative failure rate for normally operating systems increases after a few years of operation but remains relatively stable thereafter. Alternatively, the relative failure rate for systems that are primarily used in testing only is seen to increase with valve age, such that the relative failure rate for older valves, which primarily see service only for testing, is similar to that for valves that are used in normally operated systems.

Figure 3.17 shows the results of a cross-correlation of failure mode and valve age. This chart is presented specifically because there are no particularly striking features relative to valve age. That is, there is little or no correlation between age and any of the identified failure modes.

Figure 3.18 shows the relationship between valve age group and the area or source of failure. The only failure area that appears to have a continuous trend in failure rate as a function of age is the disk stud/hinge arm area. Failures in the disk stud/hinge arm area and those occurring due to the presence of foreign material were noticeably higher in the 15-20 year time period.

Figure 3.19 indicates the distribution of failures by the process being used at the time of discovery. It is particularly noteworthy that for the oldest valve group, programmatic monitoring was responsible for a significantly higher fraction of the detected failures than was the case in earlier years. The explanation for this is not clear but could possibly be attributable to lessons learned on a plant specific basis.

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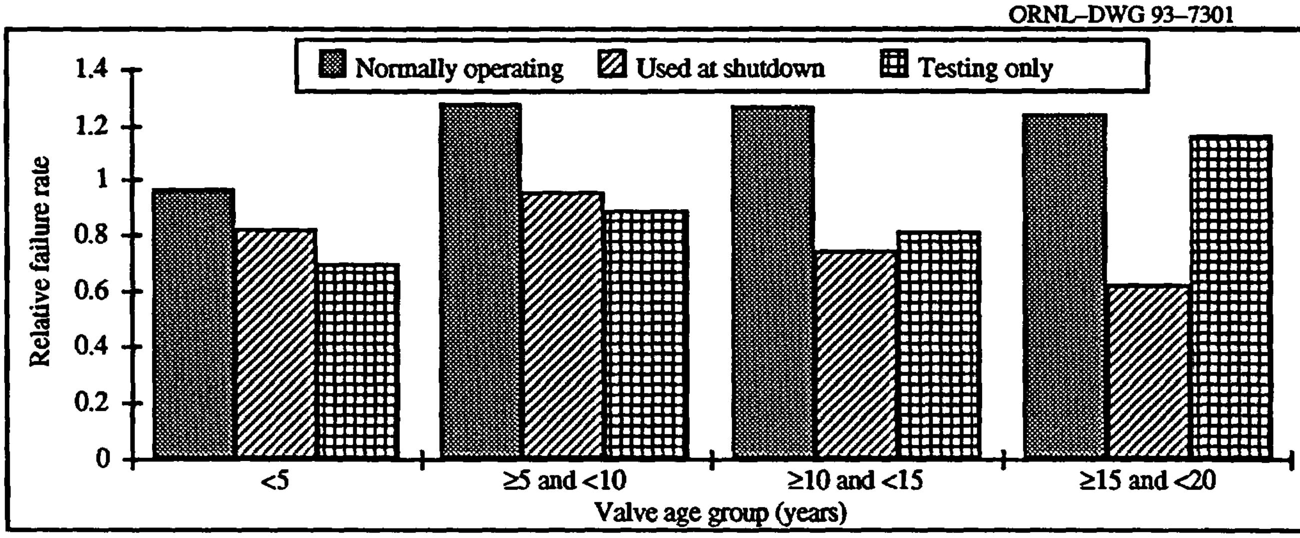

Figure 3.16 Cross-correlation of valve age group and normal system usage

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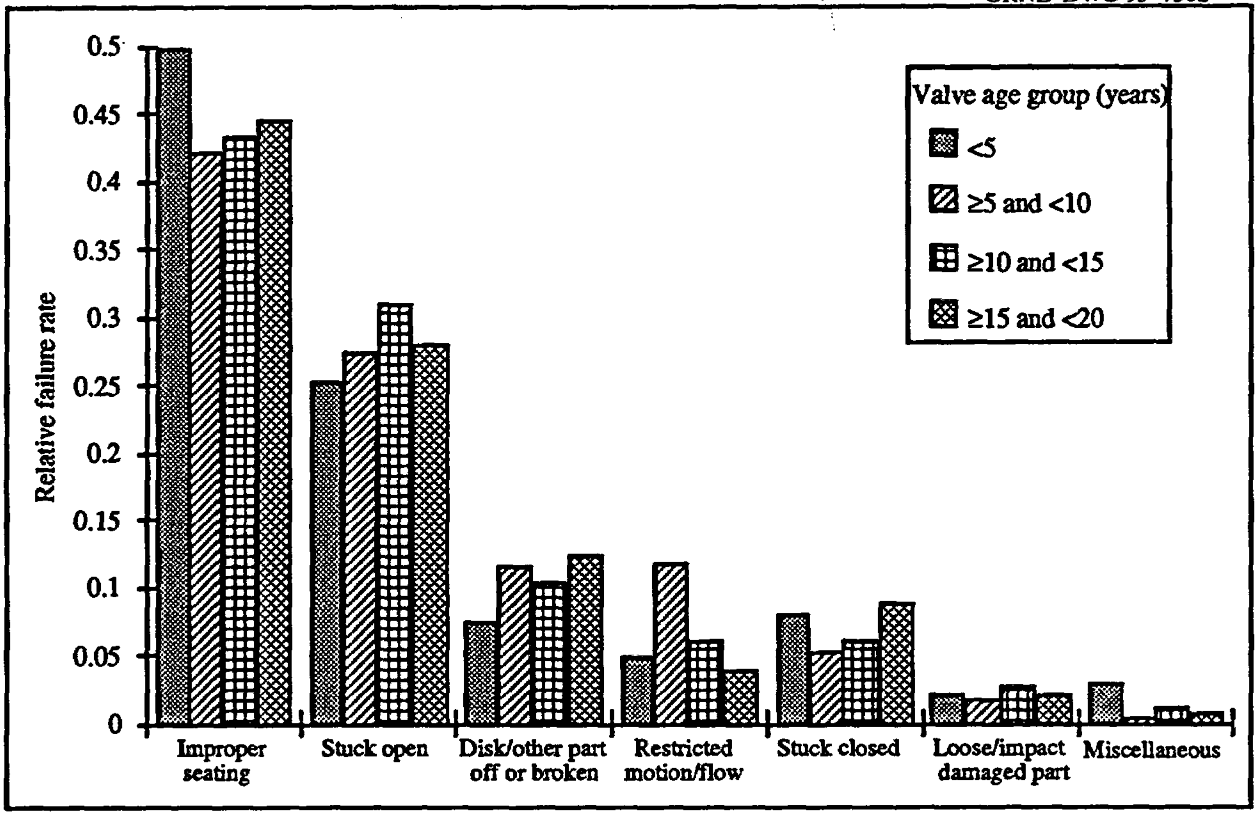

Figure 3.17 Distribution of failures by failure mode and valve age group

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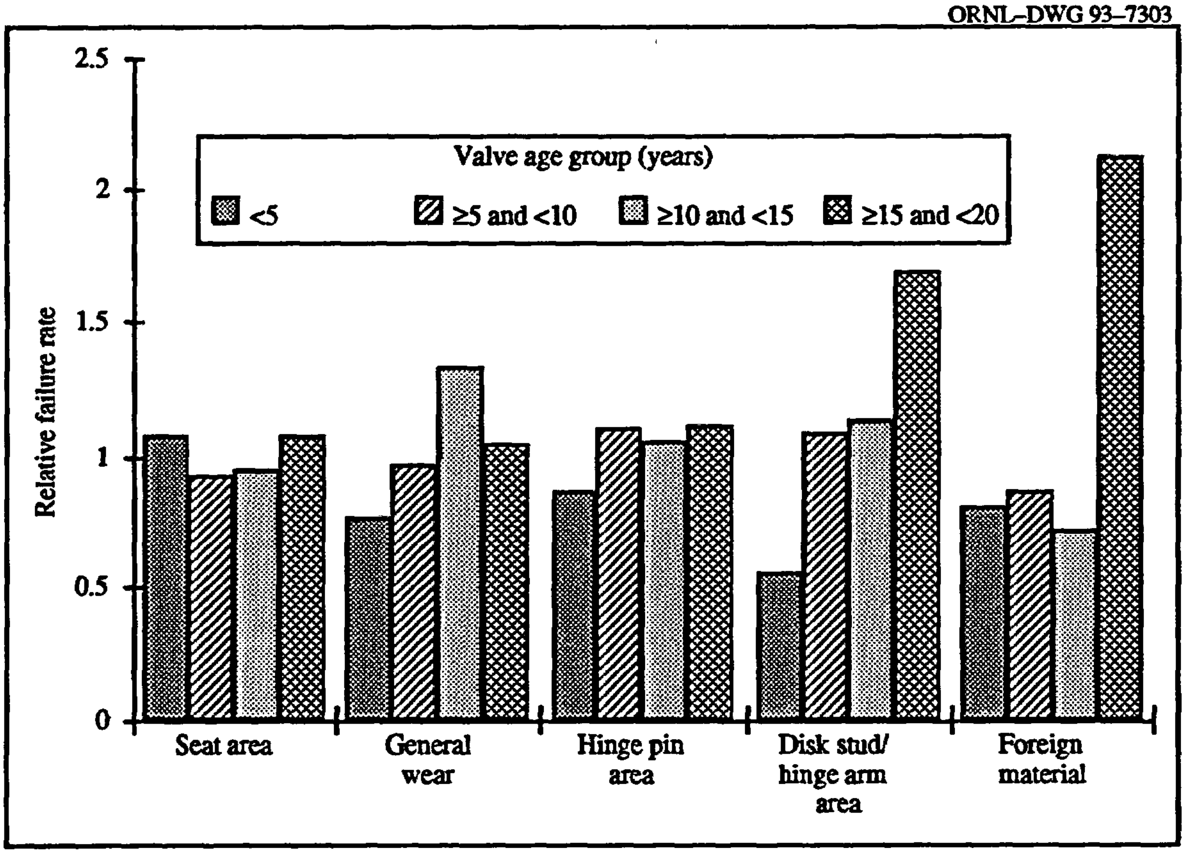

Figure 3.18 Distribution of failures by failure area and valve age group

ORNL-DWG 93-7304

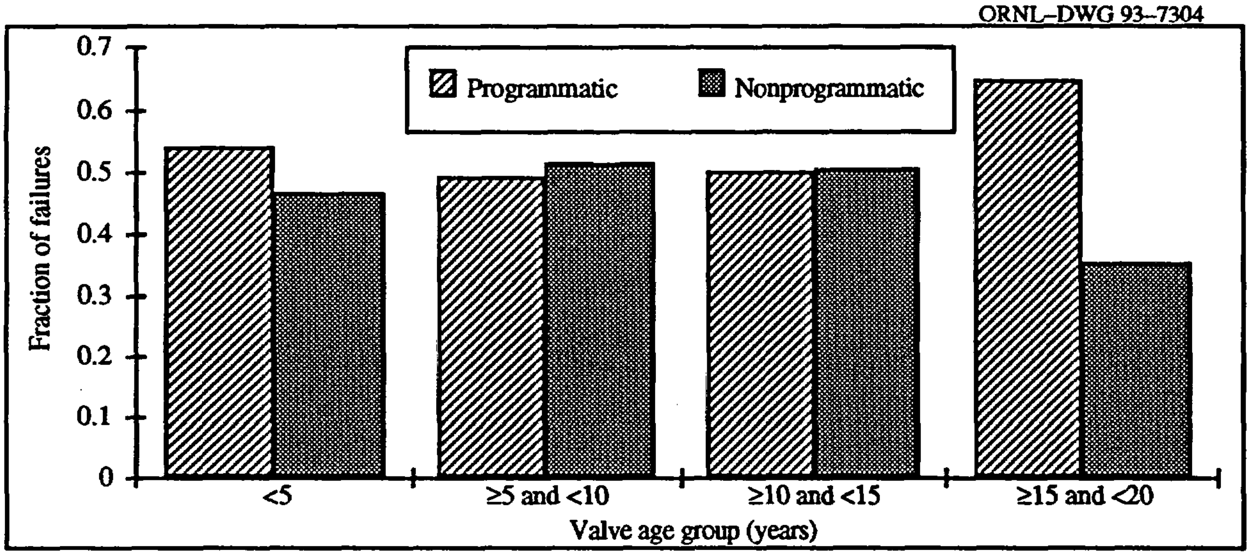

Figure 3.19 Distribution of failures by discovery process and valve age group.

3.13.2 Valve Size Group Cross-Correlations

Figures 3.20 to 3.23 show the relative failure rates for the five systems with the highest relative failure rate within each valve size group. Also shown is the distribution by failure significance. Only those systems with more than 500 valve-years of service within the specific valve size group were considered.
ESW has either the highest or second highest relative failure rate within each of the size categories.

Another interesting feature of these figures is that, generally speaking, the valves in the two larger size groups tended to have a greater fraction of their failures characterized as *Significant*, in terms of extent of degradation.

It is expected that cross-correlations such as those shown in Figures 3.20-3.23 could be useful in helping prioritize those valves to which more attention is merited. Of course other factors are important, but the valve size and system application appear to be two particularly worthwhile areas for consideration.

ORNL-DWG 93-7305

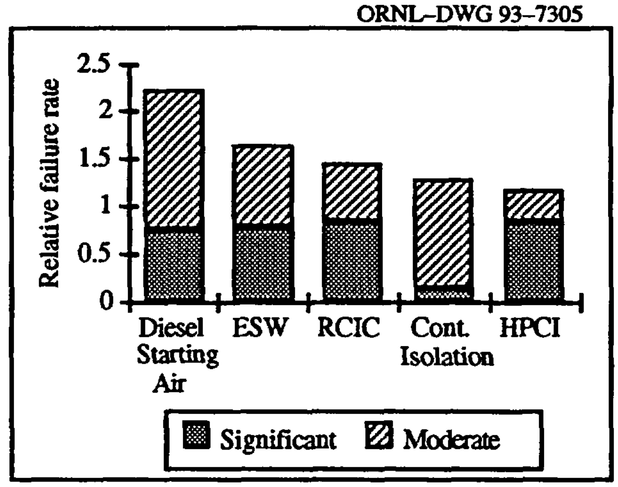

Figure 3.20 Relative failure rate and extent of degradation for valves in ≤ 2-in. size group

ORNL-DWG 93-7306

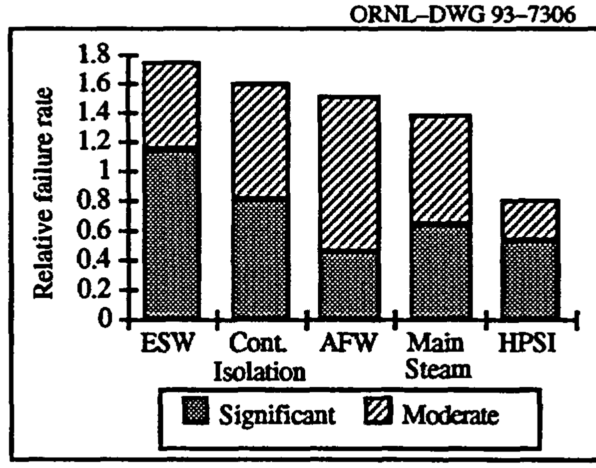

Figure 3.21 Relative failure rate and extent of degradation for valves in > 2- and ≤ 4-in. size group

ORNL-DWG 93-7307

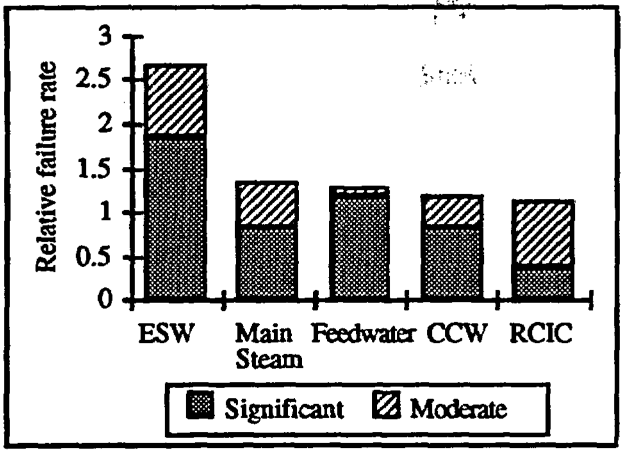

Figure 3.22 Relative failure rate and extent of degradation for valves in > 4- and ≤ 10-in. size group

ORNL-DWG 93-7308

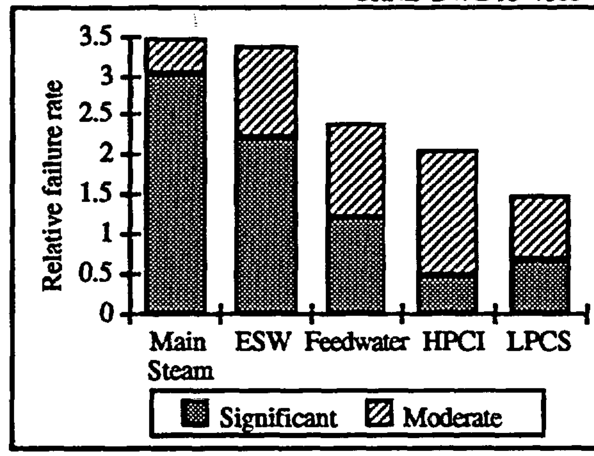

Figure 3.23 Relative failure rate and extent of degradation for valves in >10-in. size group

Figure 3.24 provides the results of the cross-correlation of valve-size group and normal system status. The relative failure rate for valves used in normally operating systems in the two smaller valve-size groups was comparable to that for valves used in the less frequently operated systems. However, for the two larger valve-size groups, the failure rate for valves used in normally operating systems was about twice that seen in the less frequently used systems. Furthermore, there is a clear trend in failure rate with valve size for normally operating systems. For the other system types, there are no clear trends.

Figure 3.25 shows the results of the cross-correlation of valve size groups and failure mode. While *Improper seating* is the leading failure mode in all four size groups, it is much more dominant for smaller valves. For the two larger valve size groups, *Stuck open* category occurs almost as frequently as *Improper Seating*. Also note that *Disk/other part off or broken* is much less significant in the smallest valve size group. Not surprisingly, *Stuck closed* is more likely to be a problem for the smaller valves, but there were *Stuck closed* cases for all valve size groups.

Figure 3.26 shows the results of a cross-correlation of valve size and failure area. Failures involving degradation in the seat area are prevalent in all valve size groups, but somewhat more problematic for the largest valve sizes. On the other hand, hinge pin area wear and disk stud/hinge arm area wear are much more significant in larger valve sizes. Foreign material is more likely to be a problem for smaller valve sizes, which may be a reflection of the fact that a given amount of foreign material can have a greater effect on a smaller valve size.

ORNL-DWG 93-7309

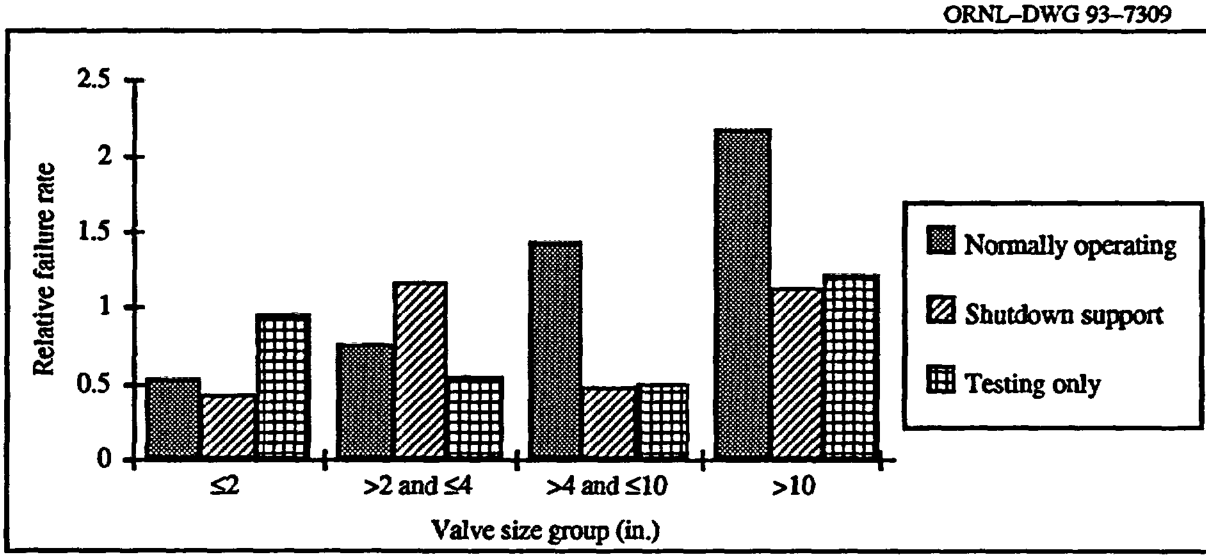

Figure 3.24 Relative failure rate by valve size group and system usage

ORNL-DWG 93-7310

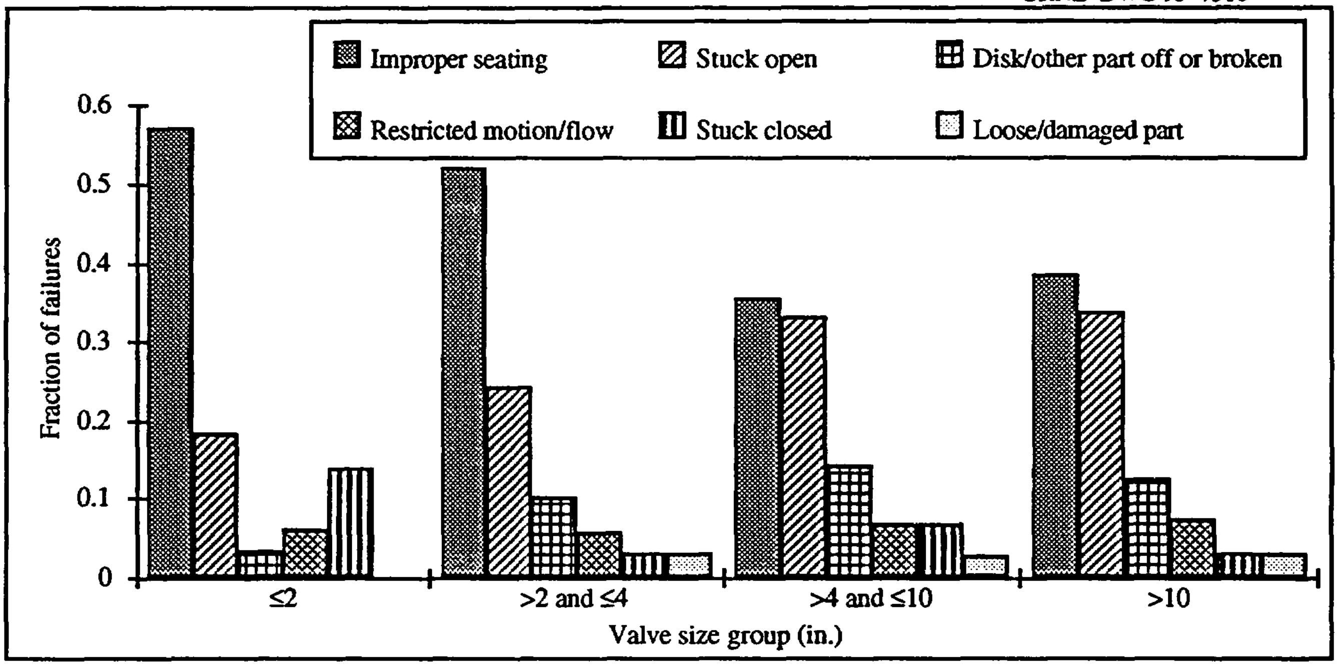

Figure 3.25 Fraction of failures by valve size group and failure mode

ORNL-DWG 93-7311

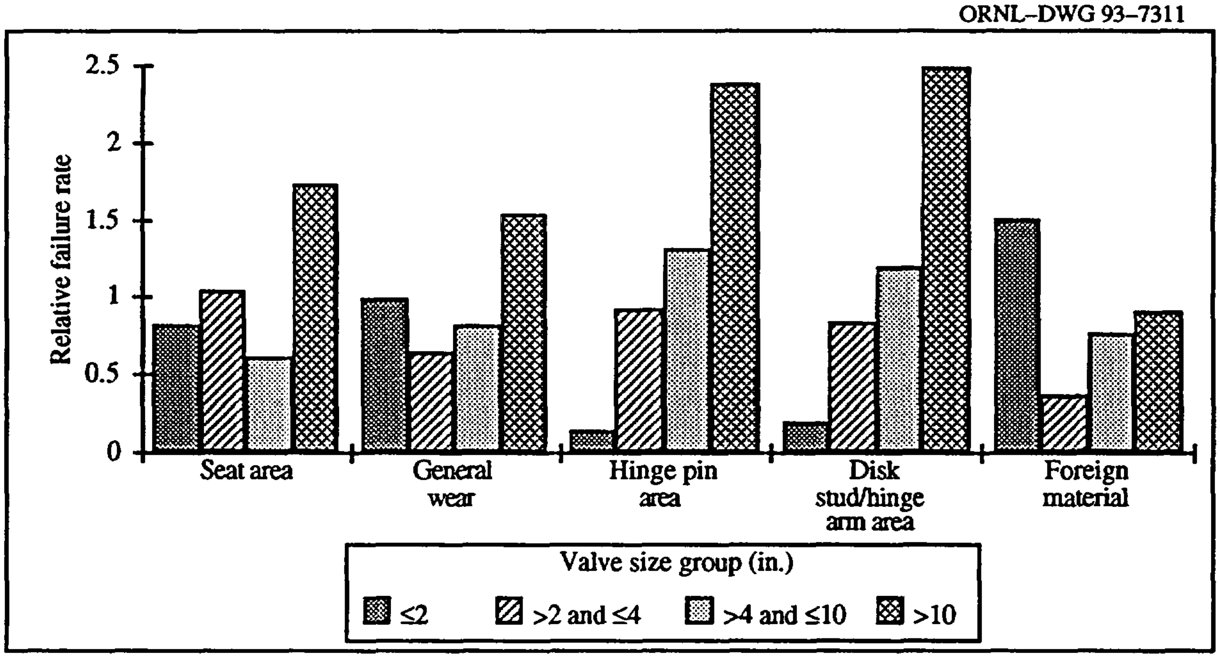

Figure 3.26 Relative failure rate by valve size group and failure area/source

The smaller fraction of failures in which *General wear* was attributed in the larger valve sizes is primarily due to the fact that in many cases, the smaller valves were simply replaced without further investigation into the specific cause or area of failure.

Figure 3.27 indicates that programmatic monitoring was more likely to be the method of failure/degradation discovery for the smaller valve size groups, while failures in the largest valve size group were more likely to be discovered nonprogrammatically. This is, no doubt, a reflection of difference in the system effect of failure of a large valve compared to failure of a small valve.

Figure 3.28 shows the relative failure rate by valve size group and extent of degradation. While the relative failure rate of both moderately and significantly degraded valves generally increase with size, the relationship of more significant failures to valve size is more distinct.

ORNL–DWG 93–7312

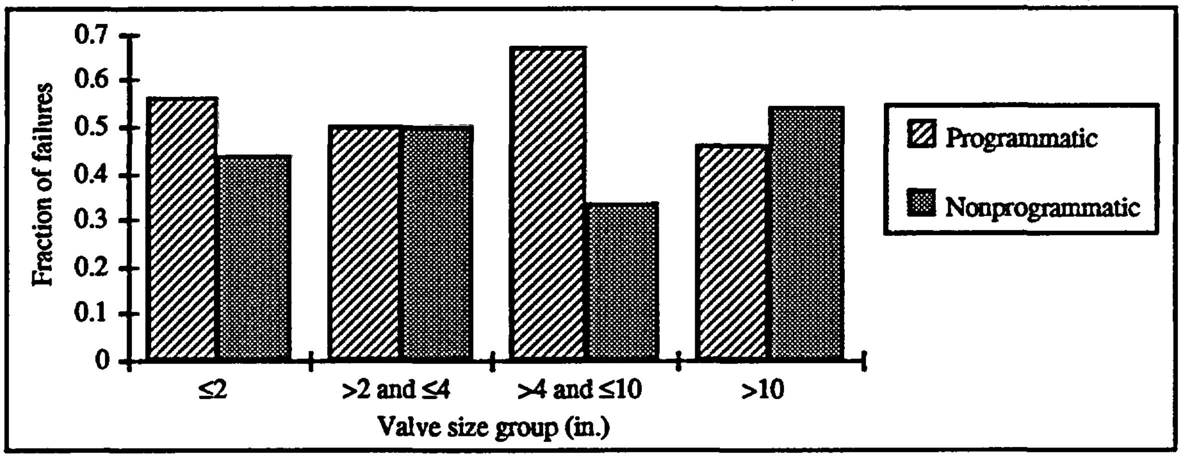

Figure 3.27 Distribution of failures by valve size group and failure discovery process

ORNL–DWG 93–7313

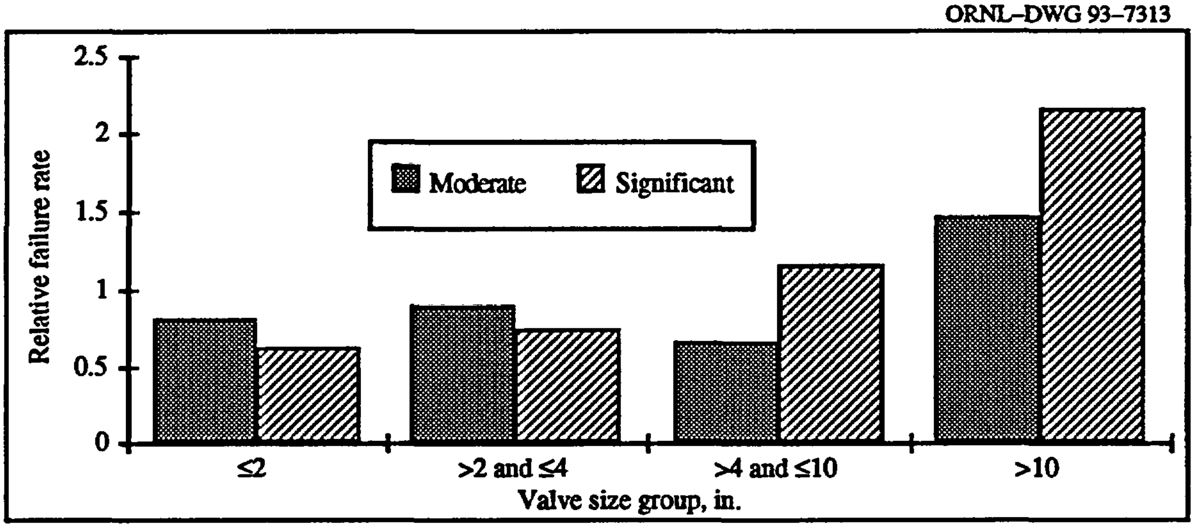

Figure 3.28 Relative failure rate by valve size group and extent of degradation

3.13.3 System Cross-Correlations

Figures 3.29 and 3.30 provide relative failure rates and population distributions by manufacturer for the five manufacturers with the highest relative failure rates within two sample systems, ESW and diesel starting air. Only those manufacturers with more than 200 valve-years service in the respective system during the study period were considered There are significant variations among the manufacturers, which are no doubt partially attributable to different applications within the systems and other factors; nevertheless, the extent of variation in relative failure rate indicates that the valve manufacturer should be a consideration in any prioritization efforts relative to valve monitoring and predictive/preventive maintenance programs.

Also note that the distribution of extent of degradation (*Moderate* or *Significant*) is substantially different for the two systems. For example, the highest relative failure rate for any manufacturer in each system is between 6 and 7; however, for ESW, the majority of these failures were deemed *Significant*, while for diesel starting air, a similar majority were deemed *Moderate*.

Figure 3.32 shows the distribution of failures in the same four systems by affected area. Considerable variations from system to system can be seen. For example, about 18 and 23% of the ESW and diesel starting air failures, respectively, involved the presence of foreign material in the valve, while relatively few feedwater or main steam valve failures were related to foreign material presence. On the other hand, about 30% of the failures in the main steam system involved penetration area problems, while the other three systems had few or no failures in that area.

ORNL–DWG 93–7314

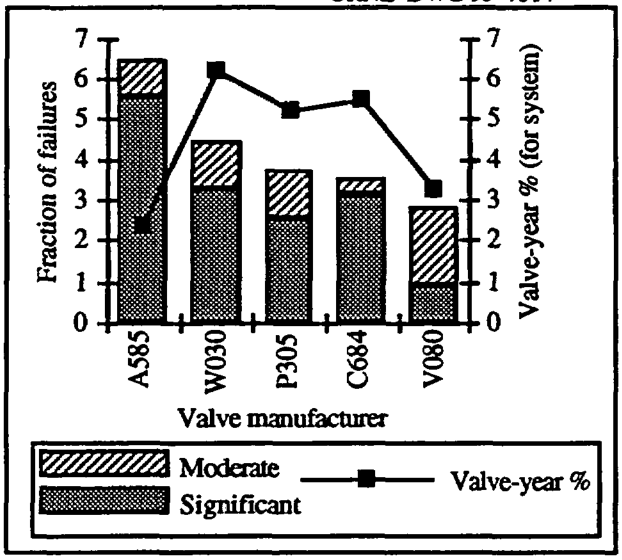

Figure 3.29 Relative failure rate (by extent of degradation) and valve population distribution for ESW system check valves for the five manufacturers with the highest failure rate within the ESW system

ORNL–DWG 93–7315

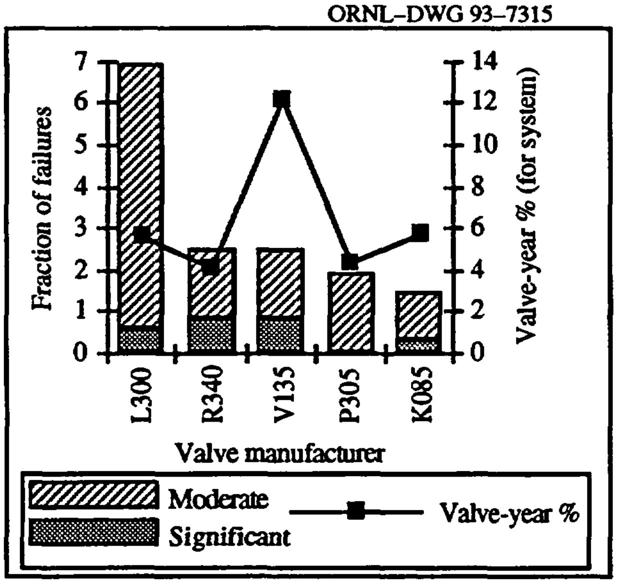

Figure 3.30 Relative failure rate (by extent of degradation) and valve population distribution for diesel starting air system check valves for the five manufacturers with the highest failure rate within the diesel starting air system

Figure 3.31 shows the distribution of failures by failure mode for the four systems with the highest overall failure rates. About 70 to 80% of the failures occurring in ESW, feedwater, and diesel starting air systems involved either improper seating or stuck open conditions, whereas in main steam, less than half the failures involved these modes. The two higher energy systems, feedwater and main steam, showed a higher tendency for disk or other parts becoming broken, as might be expected. More than 10% of the failures in the diesel starting air and main steam systems involved stuck shut conditions. It is important to point out that of the 16 cases in which main steam valves stuck shut, 12 involved failure of vacuum breakers in main steam safety relief valve discharge lines to open at the required torque. All 12 failures were observed at a single unit. Eleven of the twelve failures occurred (i.e., were discovered) within a month of each other, at about the same time the unit went commercial. All the vacuum breaker failures were attributed to hardened packing and long periods of time between valve operations. Thus, these failures within the main steam system occurred in unique applications that are not typical of steam system conditions.

Figure 3.33 indicates the distribution of failures within the four systems by specific detection method. The most obvious observation to be made is that for many of the failures (over half in the diesel starting air system), the specific method that was used to detect the failure was not discussed. Note that over one-third of the feedwater failures were detected by leak tests, in contrast with less than 5% for the other systems. Of these leak test detected failures 80% were at BWR units, the remaining 20% were at two PWR units. This is likely due to differences in leak test requirements, generally speaking, between BWR and PWR plants for main feedwater systems.

Figure 3.34 shows the distribution of failures by the process used for discovery in the ten systems with the highest overall relative failure rate. It is interesting to note that four systems (HPCI, containment isolation, RCIC, and suppression pool support) had significantly higher fractions of the failures detected programmatically than did the other systems. Three of the four systems (HPCI, RCIC, and suppression pool support) are exclusively BWR systems, while the containment isolation valves are exclusively at PWR plants.* The relatively high rate of programmatically detected failures in these systems is attributable to required leak testing for many valves used therein.

The distribution of failures by extent of degradation for these ten systems is shown in Figure 3.35. Considerable variations in extent of degradation can be seen. For example, about two-thirds of the ESW and main steam failures were deemed *Significant*, while only about one-fifth of the containment isolation failures were so designated This result is not unexpected in light of typical service conditions as well as variations in typical test methodologies.

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* Clearly, many valves in a variety of BWR and PWR systems function as continent isolation valves. In NPRDS, *containment isolation* is a system into which valves that act as containment isolation valves, but do not fit in any other NPRDS system are placed.

ORNL-DWG 93-7316

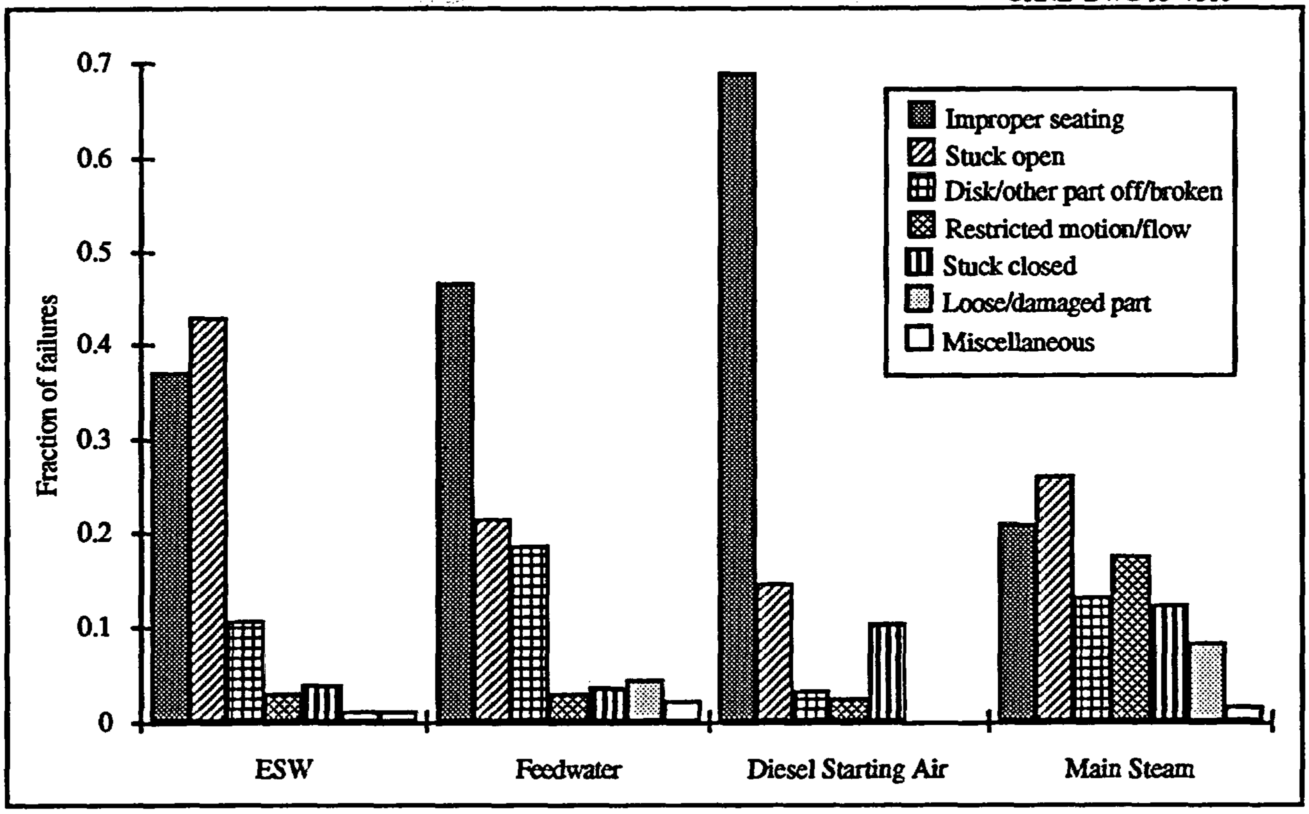


Figure 3.31 Distribution of failures by failure mode for four systems with the highest overall failure rate

ORNL-DWG 93-7317

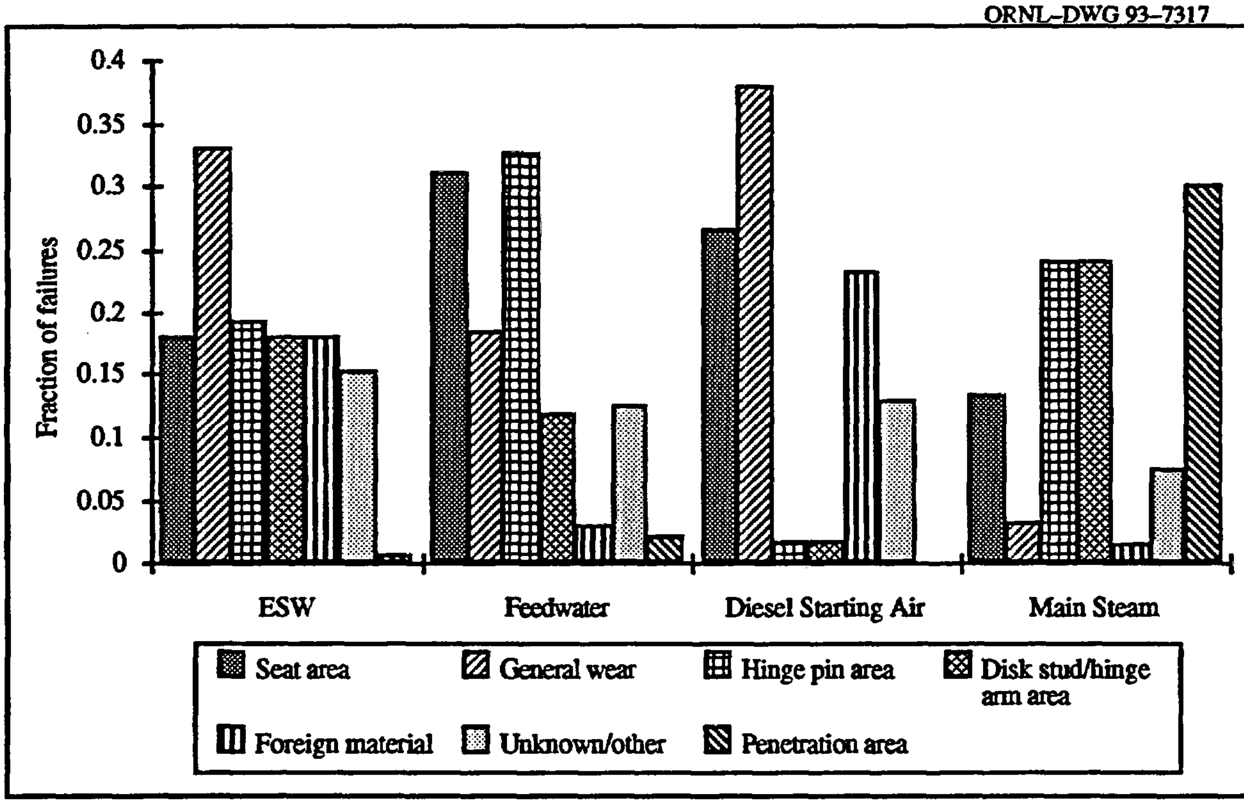


Figure 3.32 Distribution of failures by failure area for four systems with the highest overall failure rate

ORNL-DWG 93-7318

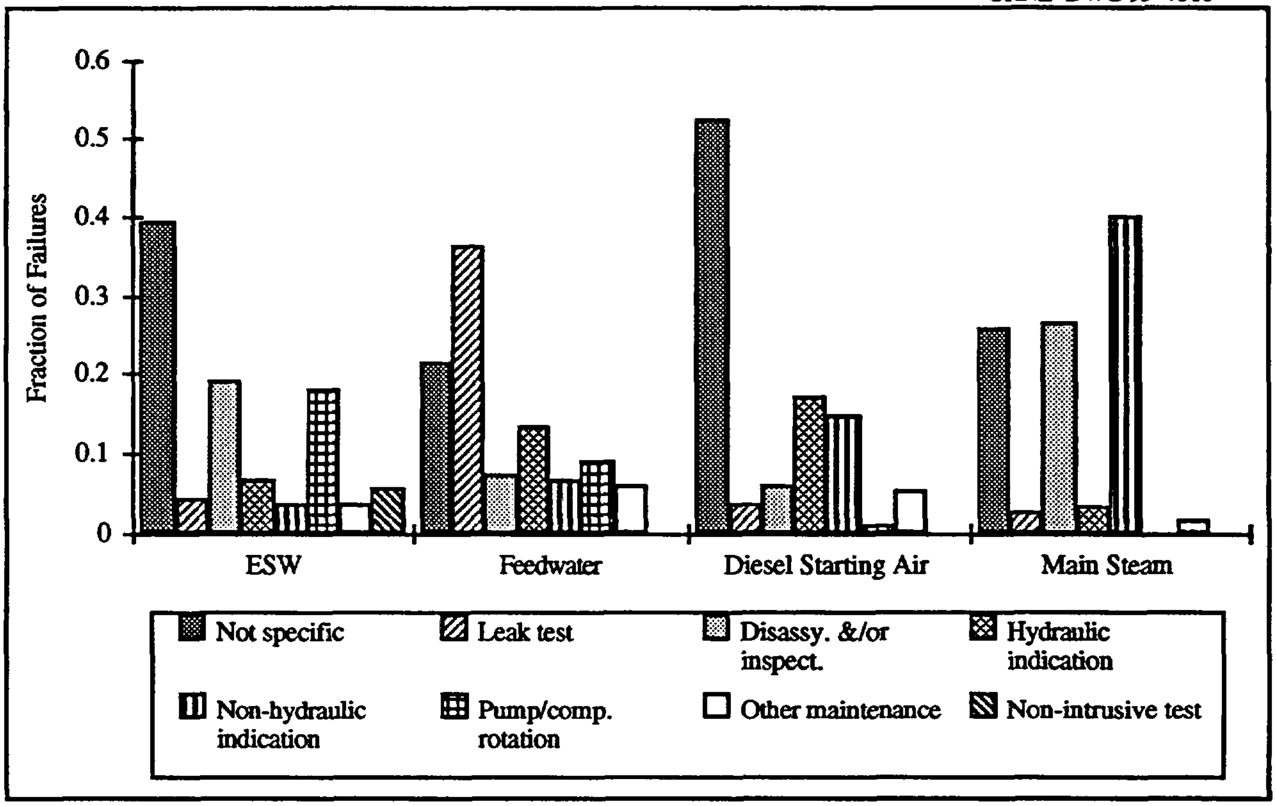


Figure 3.33 Distribution of failures by specific detection method for four systems with the highest overall failure rate

ORNL-DWG 93-7319

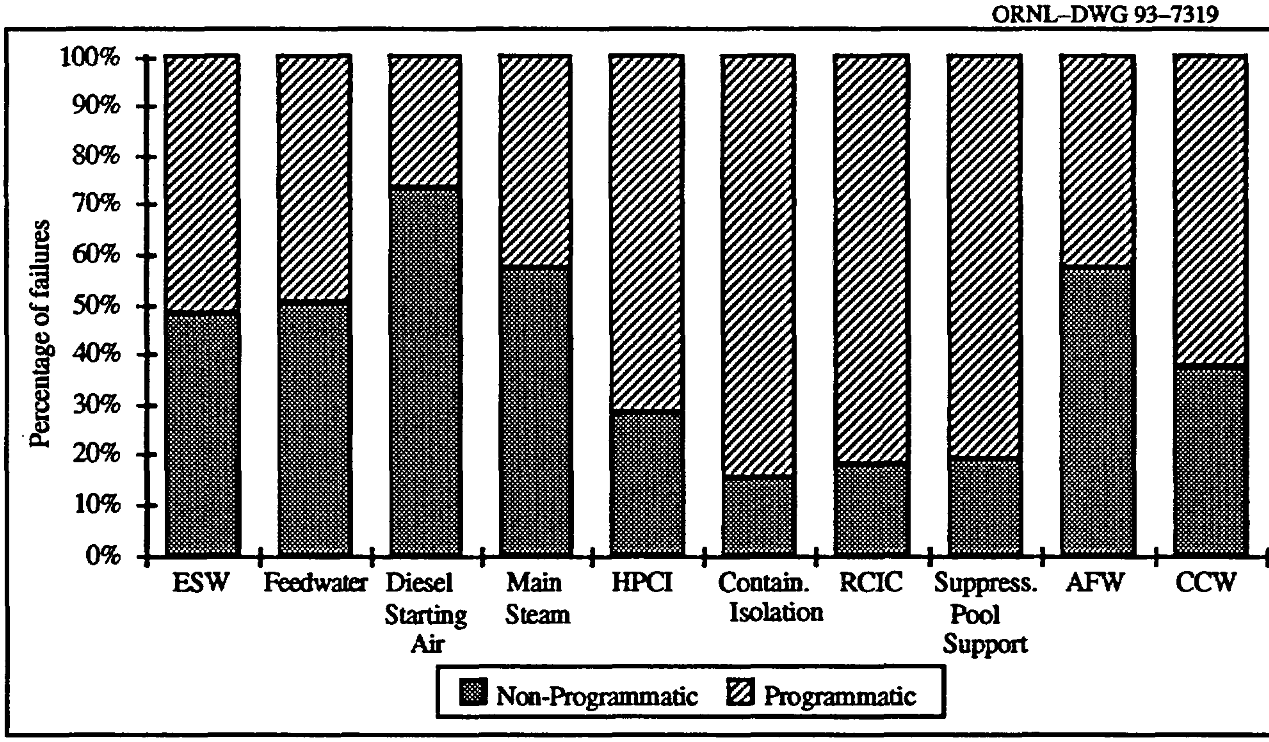


Figure 3.34 Distribution of failures by discovery process for ten systems with the highest overall failure rate

ORNL–DWG 93–7320

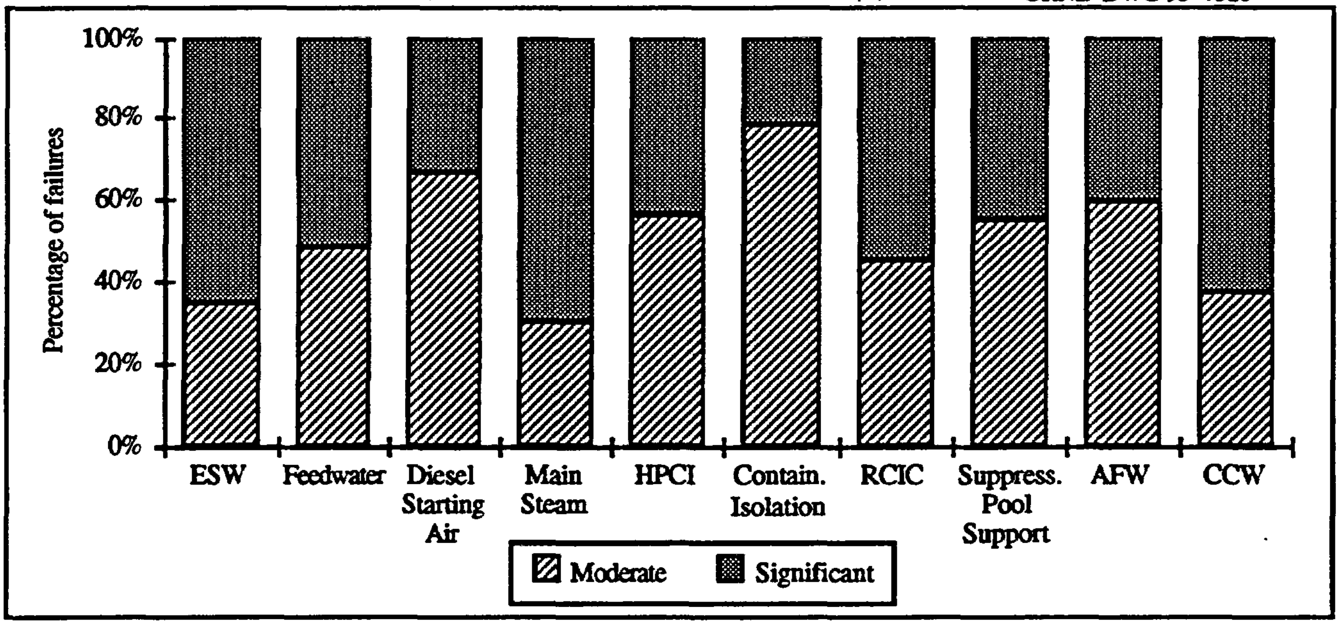


Figure 3.35 Distribution of failures by extent of degradation for ten systems with the highest overall failure rate

3.13.4 Manufacturer Cross-Correlations

When comparing the relative failure rates of specific manufacturers, special care should be exercised. This is clearly manifested by re-examining Figures 3.29 and 3.30, which provide relative failure rates by extent of degradation for the five manufacturers with the highest relative failure rates in the ESW and diesel starting air systems. While the overall relative failure rates are similar, the extent of degradations vary considerably.

Figure 3.5 provided the relative failure rates for all manufacturers with more than 1000 valve-years of service during the study period. Figure 3.36 provides the relative failure rate, by valve size, for the ten manufacturers with the highest overall relative failure rate. From this figure, it can be inferred that the two manufacturers with the overall highest failure rate were significantly affected by the fact that they had relatively few small valves in service (no failures of the ≤2-in. size group). Further investigation showed that, in fact, valves supplied by these two manufacturers combined provided <5% of all operating experience during the study period for all valve sizes combined, but over 15% of the operating experience for the >10-in. valve size group.

ORNL–DWG 93–7321

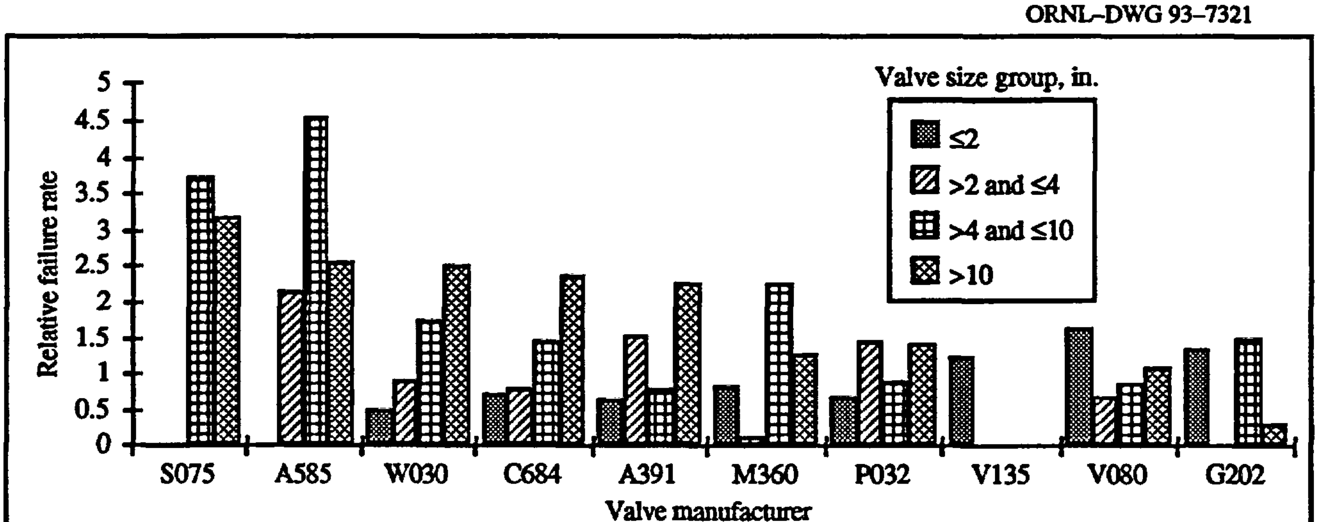


Figure 3.36 Relative failure rate by manufacturer and valve size group for ten manufacturers with highest overall failure rate

In addition to the influence associated with size , the system application affects the relative failure rate. The two manufacturers with the highest overall failure rate not only had a disproportionate number of larger size valves, they also had a disproportionate number of valves in feedwater and main steam system service. Recall that these two systems are among the four highest failure rate systems. Over 15 and 20% of the experience for feedwater and main steam system check valves, respectively, was provided by these two manufacturers, which, as noted above, provided <5% of the overall operating experience.

Thus, while these manufacturer's valves do appear to have relatively high failure rates, the population distribution by valve size, system application, and other variables have a significant bearing on the overall relative failure rate.

These examples show the potential for drawing erroneous conclusions from the top-level assessments. Even with the cross-correlated analyses shown here, there are a variety of factors that influence failure rates for the individual manufacturers, such as severity of service duty; thus, the manufacturer results (in particular) should be used circumspectly.

3.13.5 NSSS Cross-Correlations

As was noted previously, BWR units had a higher overall relative failure rate than PWRs (see Figure 3.6). One of the reasons for this discrepancy is shown in Figure 3.37. Clearly, BWR plants detect a significantly higher fraction of failures by programmatic means than do PWRs. This is likely a direct result of the fact that not only do BWRs include more valves in their in-service test programs, they also typically leak-test a greater number of valves. Figure 3.37 illustrates the potential for drawing improper conclusions from the data and reinforces the importance of carefully examining any apparent trends or features to ensure that causal factors are understood.

ORNL-DWG 93-7322

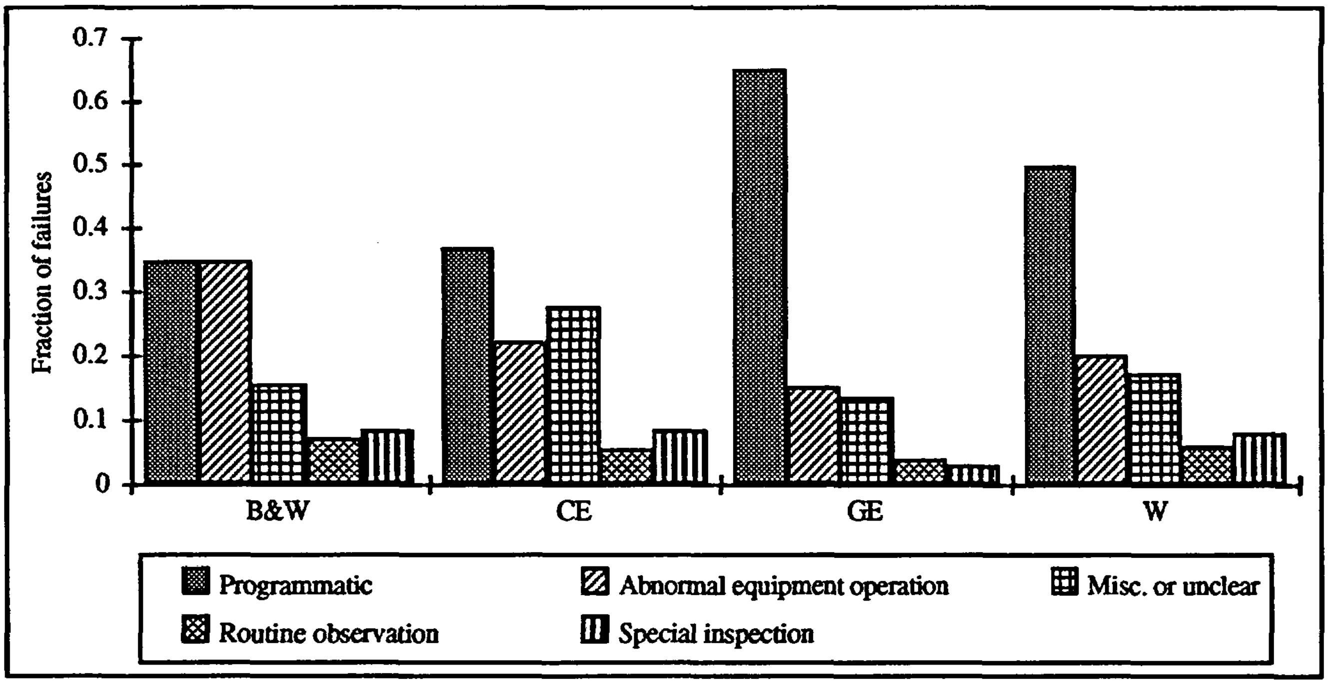


Figure 3.37 Distribution of failures by general detection method and NSSS

3.13.6 System Usage Cross-Correlations

In Figure 3.8, it was shown that almost half the failures were associated with improper seating; thus this failure mode has a significant impact on the overall failure distribution. From Figure 3.38 it can be seen that although the relative failure rate for improper seating failures is essentially the same for all three types of system usages, there are significant differences in other failure modes. *Stuck open*, *Disk/other part off or broken*, *Stuck closed*, and *Loose/impact damaged part* failure modes generally represent more significant degradation than does *Improper seating*. The relative failure rates for these failure modes certainly vary according to system usage. For instance, the relative failure rate for normally operating valves in the *Stuck open* failure mode is about twice that for systems used in shutdown support or in testing only. However, systems used for testing only are more likely to be affected by *Stuck closed* failures than are normally operated systems. This observation is even somewhat understated in that a significant number of the *Stuck closed* cases for normally operating systems involved vacuum breakers that are infrequently exercised, and thus they are similar in usage to most testing only systems valves.

Figure 3.39 shows the overall distribution of extent of degradation within each of the three system usage categories. While not dramatic, there is a slight trend toward an increased proportion of failures that are more significant in nature with increased system usage (i.e., the normally operating systems have a slightly greater fraction of *significant* failures than shutdown support systems, which in turn have a slightly greater fraction than testing only systems).

ORNL-DWG 93-7323

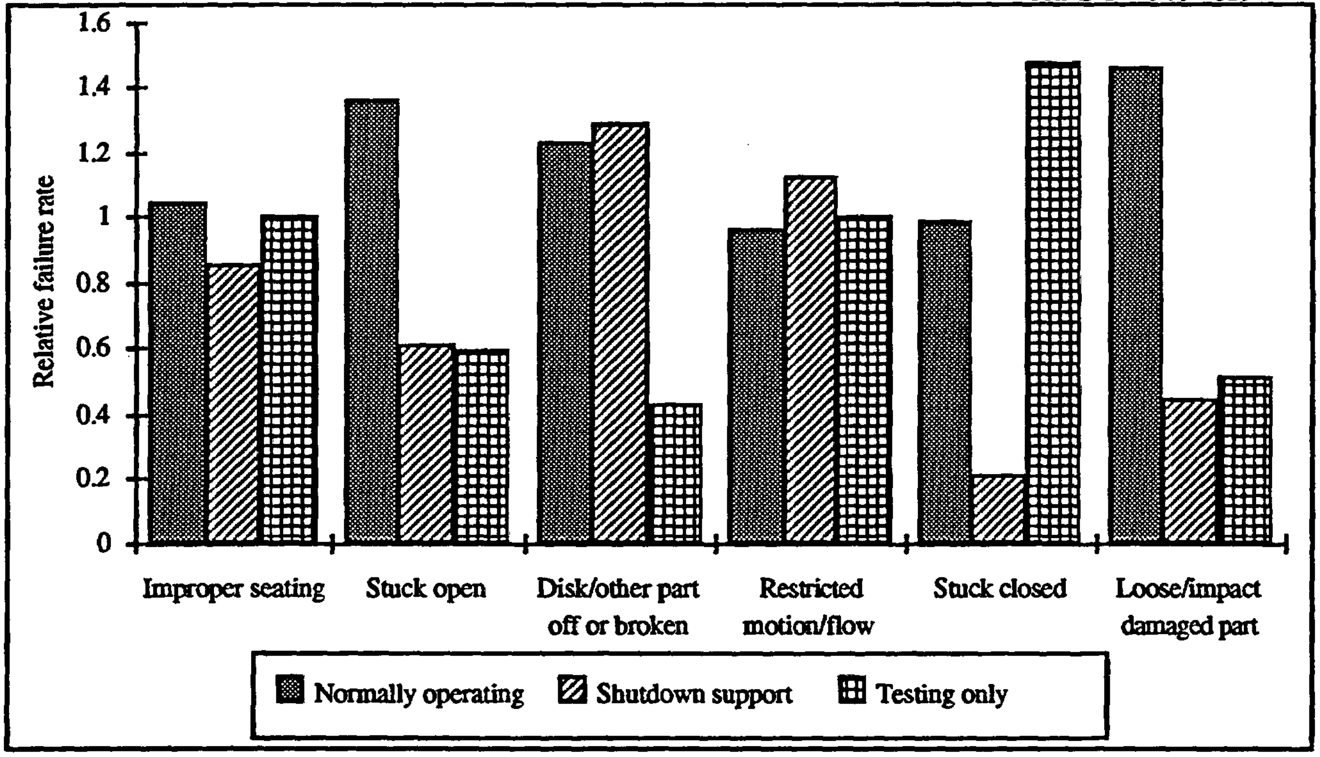


Figure 3.38 Relative failure rate by system usage and failure mode

ORNL-DWG 93-7324

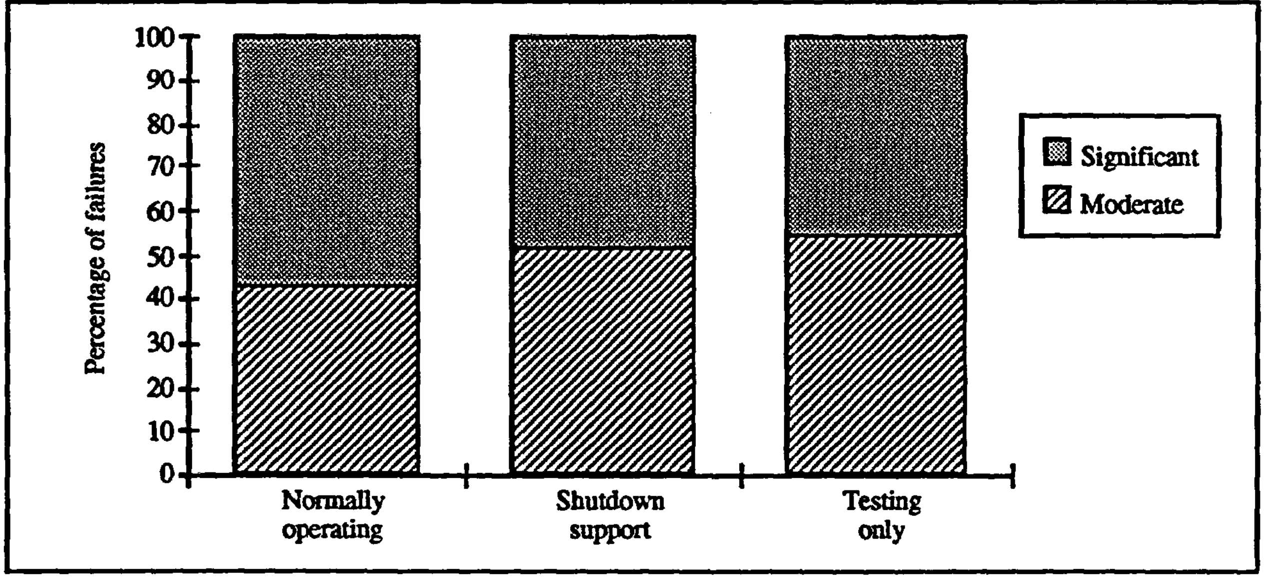


Figure 3.39 Distribution of failures by system usage and extent of degradation

3.13.7 Failure Mode Cross-Correlations

Figure 3.40 shows the fraction of failures by failure mode and general detection method. This figure indicates that the types of programmatic monitoring historically applied have been more successful at detecting *improper seating, stuck closed*, and *loose/damaged parts* than the other failure modes, particularly *disk/other part off or broken*. However, opportunity for improving the programmatic detection of all the failure modes exists.

For the *disk/other part off or broken* failure mode, special inspections have been the second most successfully applied technique. Further review indicated that about one-third of the programmatically detected failures were detected by disassembly and examination (conducted as part of a preventive maintenance or other routinely applied inspection program); thus almost 40% of the *disk/other part off or broken* failures were found as the result of valve disassembly and inspection.

ORNL–DWG 93–7325

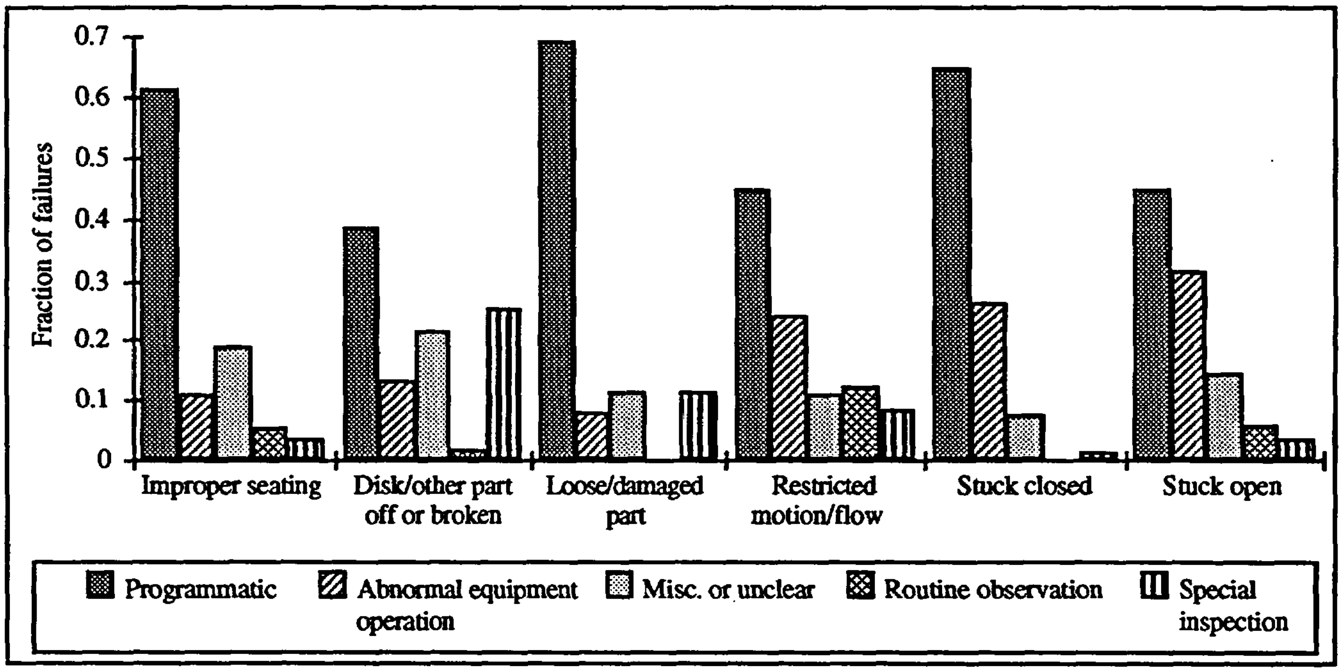


Figure 3.40 Distribution of failures by failure mode and general detection method

3.13.8 Failure Area Cross-Correlations

Figure 3.41 provides the distribution of failures by failure area and discovery process. Degradation due to the presence of foreign material and seat area-related problems was most likely to be detected programmatically. Disk stud/hinge arm area problems were least likely to be detected programmatically. Figure 3.42 shows that the two areas for which the extent of degradation was judged to be greatest were the penetration and disk stud/hinge arm areas. The combination of these two charts (along with the raw number of failures classified as significant in nature) indicates that the area in greatest need of improved monitoring is the disk stud/hinge arm area.

ORNL-DWG 93-7326

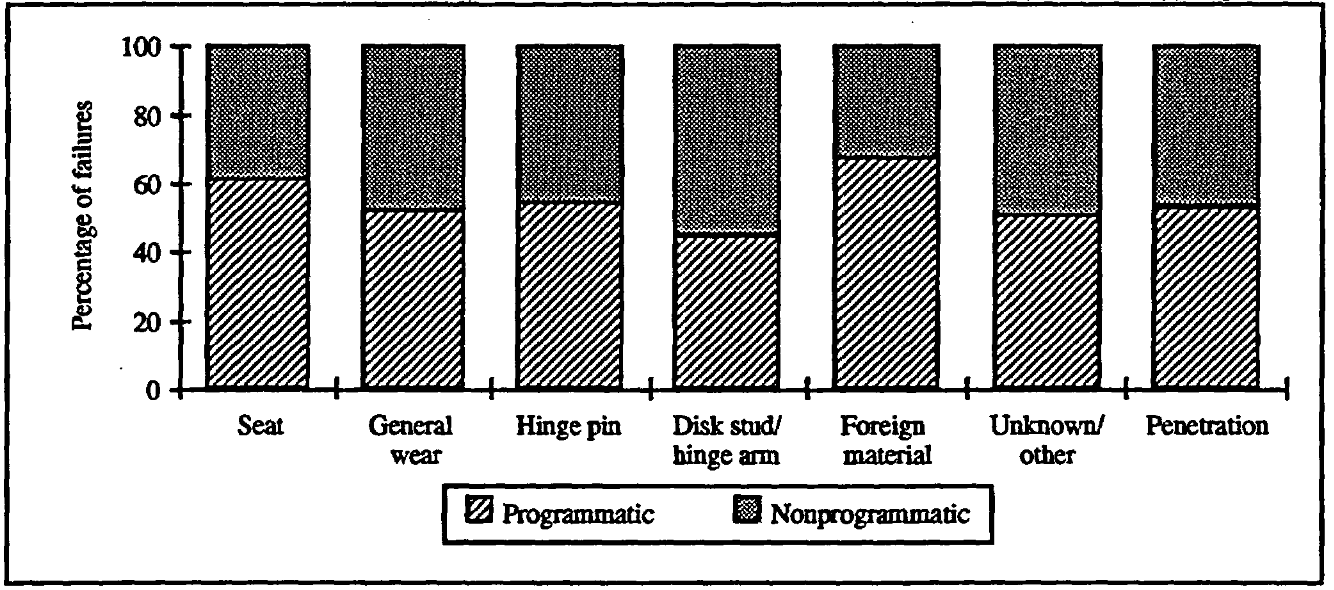


Figure 3.41 Distribution of failures by failure area and discovery process

ORNL-DWG 93-7327

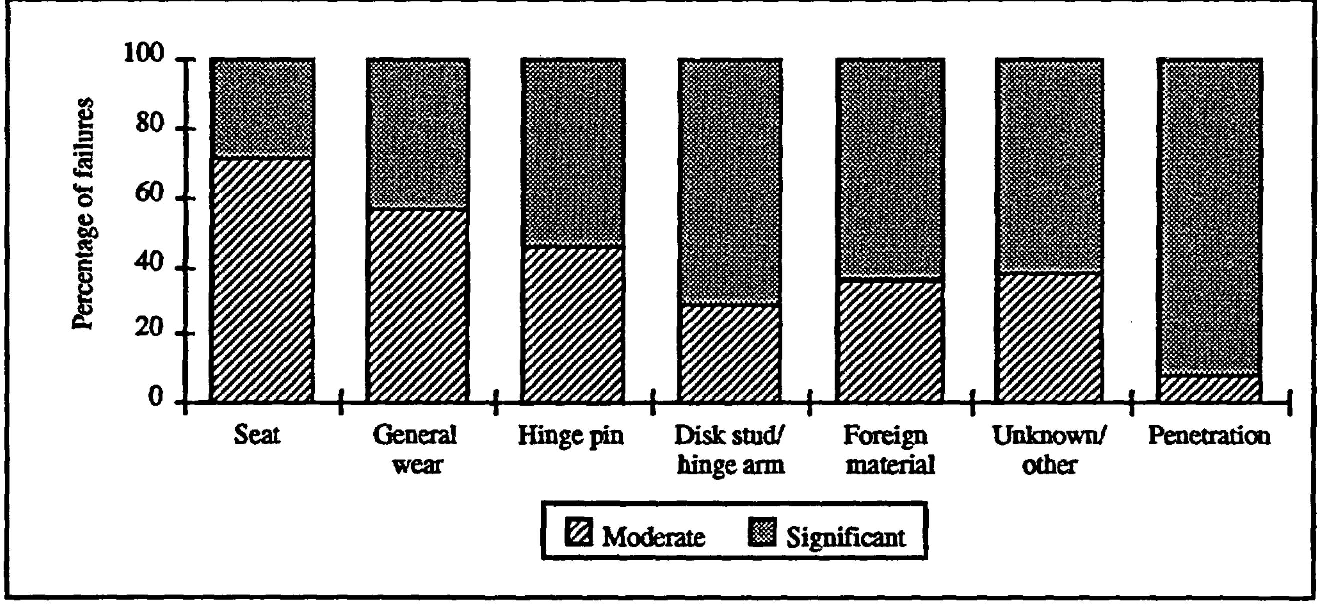


Figure 3.42 Distribution of failures by failure area and extent of degradation

3.13.9 General and Specific Detection Method Cross-Correlations

Figure 3.43 provides the distribution of failures by general detection method and extent of degradation. As expected, a relatively high fraction of failures discovered as the result of *abnormal equipment operation* (e.g., pump reverse rotation) were judged to be significantly degraded. Another general detection method with a relatively high fraction of significant failures was *special inspection.*

Figure 3.44 shows the extent of degradation by specific detection method. Other than those failures for which the specific method of detection was indeterminate, leak testing was the most frequent detector of degraded internals. However, as indicated in Figure 3.44, over 80% of the failures detected by leak testing were classified as moderate in extent of degradation. On the other hand, a substantial portion of failures detected by several other specific detection methods, such as *nonintrusive testing, disassembly and inspection*, and *pump/compressor reverse rotation* involved a more significant level of degradation.

ORNL-DWG 93-7328

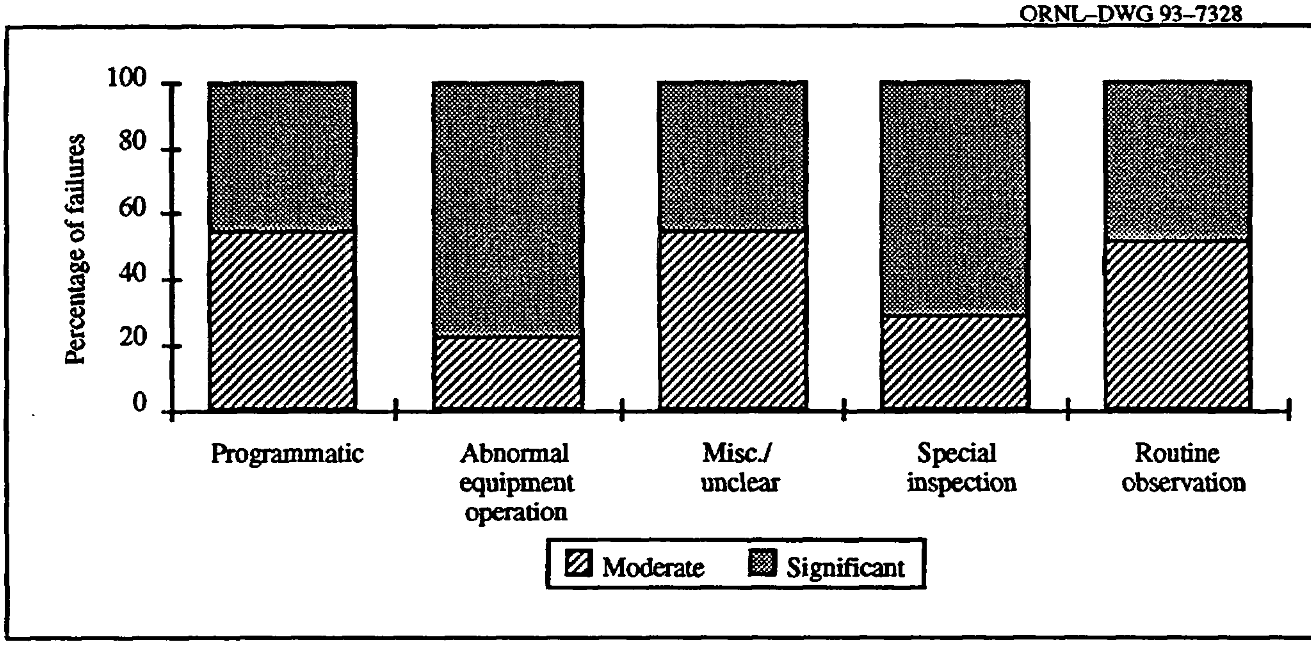


Figure 3.43 Distribution of failures by general detection method and extent of degradation

ORNL-DWG 93-7329

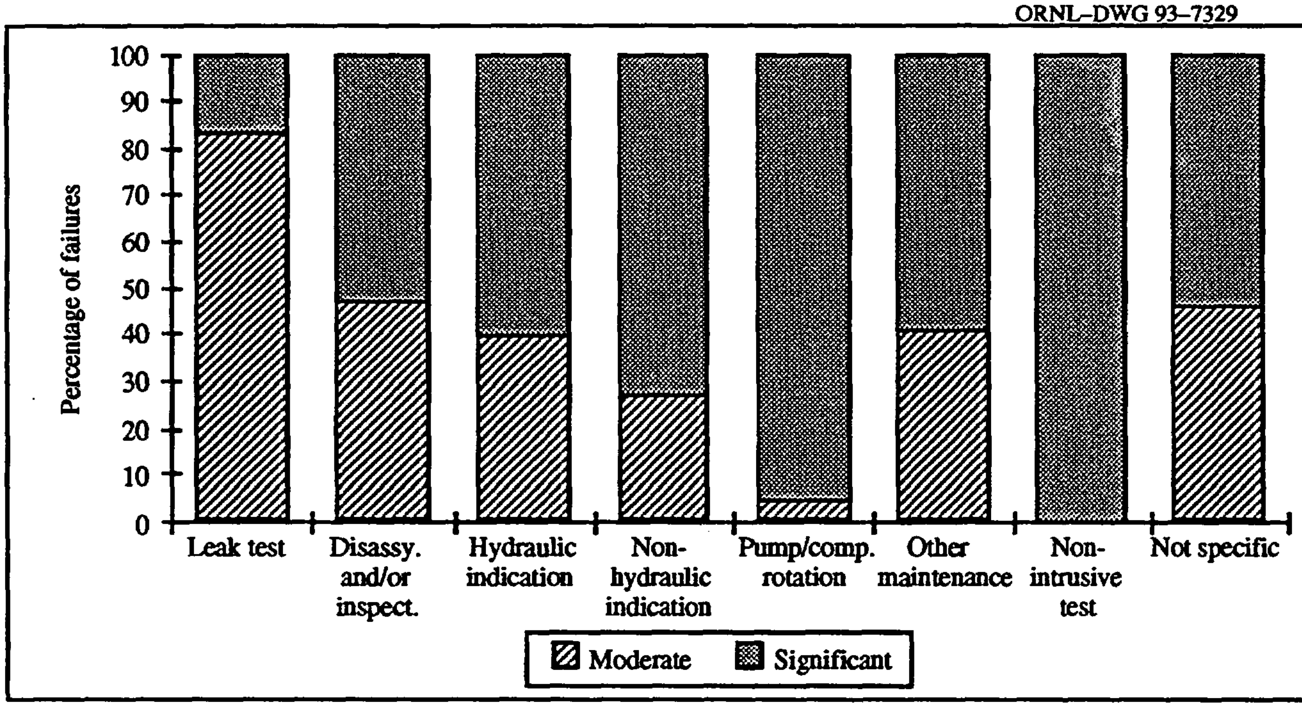


Figure 3.44 Distribution of failures by specific detection method and extent of degradation

3.13.10 Discovery Process Cross-Correlations

Several of the previous cross-correlation sections have provided indication of discovery process correlations with the other parameters. This section will cover some aspects that were not previously addressed.

Figure 3.37 showed that BWR plants were more likely to detect failures programmatically than their PWR counterparts, when the failure data was cross-correlated with the general detection method. Another perspective on the relative levels of degradation detection processes is provided by Figure 3.45, which highlights the distinction between the discovery processes at BWR plants and PWR plants. Reference was made to the fact that BWR plants typically include more valves in in-service test programs, as well as leak testing a greater number of valves. In addition, it has been observed that, generally speaking, BWR plants simply made better design provision for in-service testing than did many PWR units (for example, generically providing full-flow test lines for safety-related pumps).

Figure 3.46 indicates that there is no correlation between the percentage of failures discovered programmatically and the type of system in which the failed valve is used. This is somewhat surprising, inasmuch as it would appear reasonable to presume that failures of valves in normally operating systems would tend to manifest the failures more readily than would less frequently used systems. The explanation may lie in the fact that improper seating is the type of condition that would most readily manifest itself outside of testing, and the likelihood of this failure mode was found to be not particularly dependent upon the system usage (refer to Figure 3.38).

ORNL-DWG 93-7330

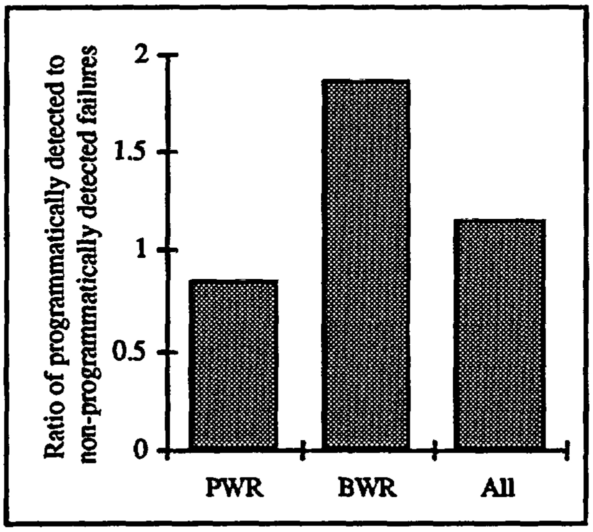


Figure 3.45 Comparison of discovery processes for different type facilities

ORNL-DWG 93-7331

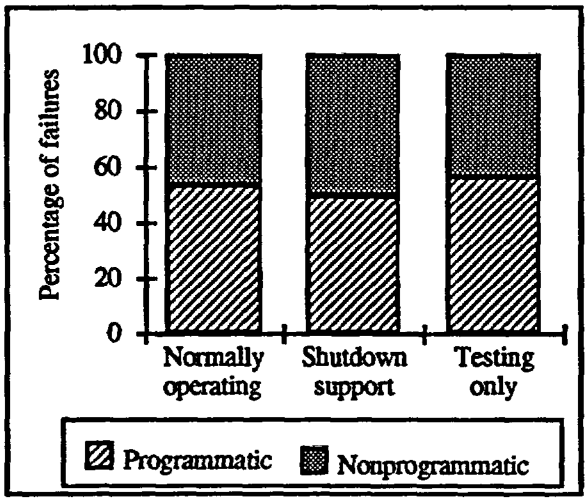


Figure 3.46 Comparison of discovery processes for different system usages

3.13.11 Extent of Degradation Cross-Correlations

Figures 3.21 through 3.23 show that for a given system, there are variations in the extent of degradation distribution according to size. For example, about one-third of the ESW failures in the ≤2-in. size group were classified as *Significant*, while about two-thirds of the ESW failures in the >10-in. size group were *Significant* in nature.

Figures 3.21 through 3.23 show there are variations in extent of degradation from system to system within the individual size groups. For example, in the ≤2-in. size group, diesel starting air valves have the highest overall failure rate; yet the rate of failures that were more significant in nature was highest for HPCI valves, which had the fifth highest overall failure rate for the size group.

Figure 3.4 shows the relative failure rate for all failures characterized in this study. Figure 3.35 shows the variation in distribution of failures by extent of degradation for the ten systems with the highest overall failure rate. The systems in Figure 3.35 are arranged from left to right in descending order of relative failure rate.

Figure 3.47 provides the relative failure rates by system for only those failures that were categorized as *Significant*. ESW is still the system with the highest relative failure rate; in fact, the relative failure rate for *Significant* failures in ESW is greater than its relative failure rate overall. It can also be seen that the relative failure rate for the diesel starting air system is reduced when considering the *Significant* failures only, such that only three systems — ESW, main steam, and feedwater — are noticeably higher than the remainder. Also note that less than half of the failures for these three systems were detected programmatically.

Figure 3.48 shows the distribution of failures by general detection method and level of significance. More of the *Moderate* failures were detected programmatically than the *Significant* failures. Alternatively, more *Significant* failures were detected as the result of abnormal equipment operation than moderate failures. The latter is not unexpected, because the likelihood of abnormal equipment operation should increase with increased valve degradation.

Figure 3.49 shows the relative failure rate by valve size and system usage for failures classified as *Significant* only. A pattern seen for all failures (Figure 3.25) was found to hold true for this subset as well; that is, for the smaller valve sizes, the relative failure rates for the three system usage categories are similar, but for the larger valve sizes, normally operating systems were much more likely to have failures. In fact the pattern is somewhat more dramatic for the *Significant* failure class.

ORNL–DWG 93–7332

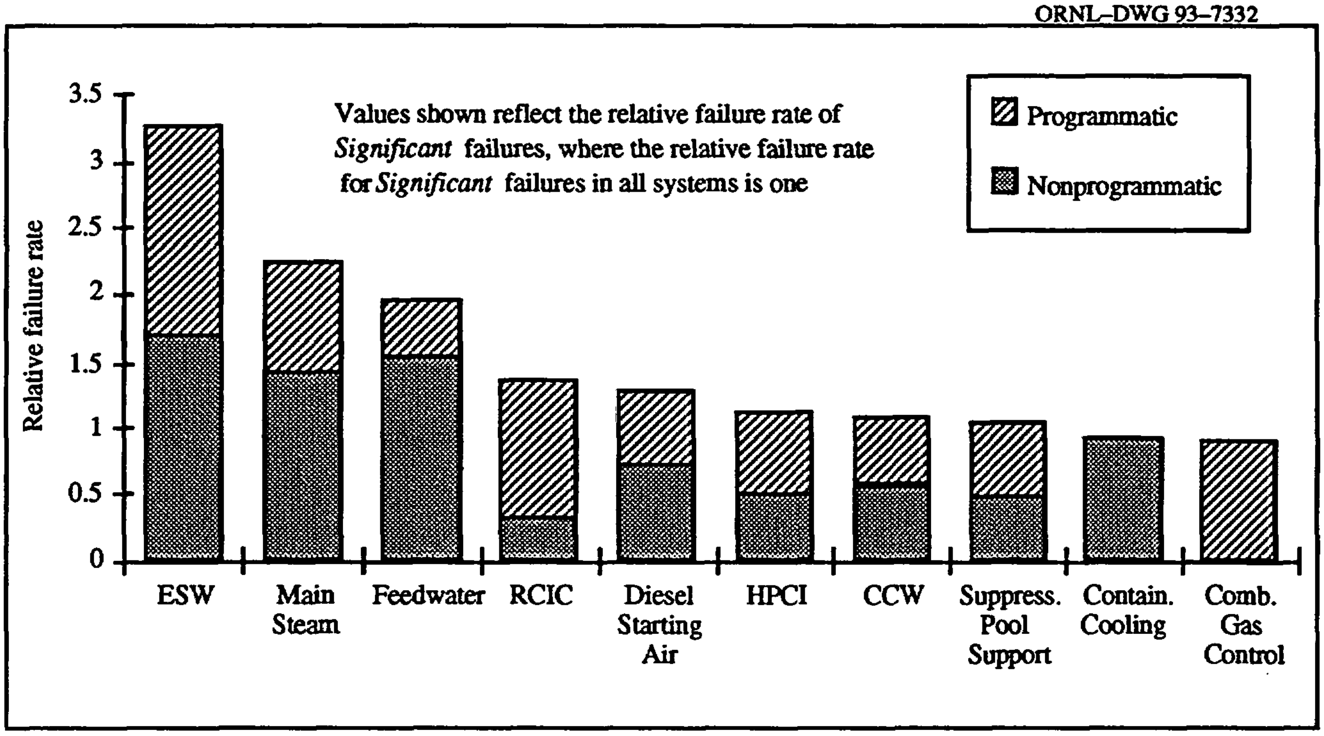


Figure 3.47 Relative failure rate, by discovery process, for failures designated as *significant*. Systems shown are the ten systems with the highest relative failure rates

ORNL–DWG 93–7333

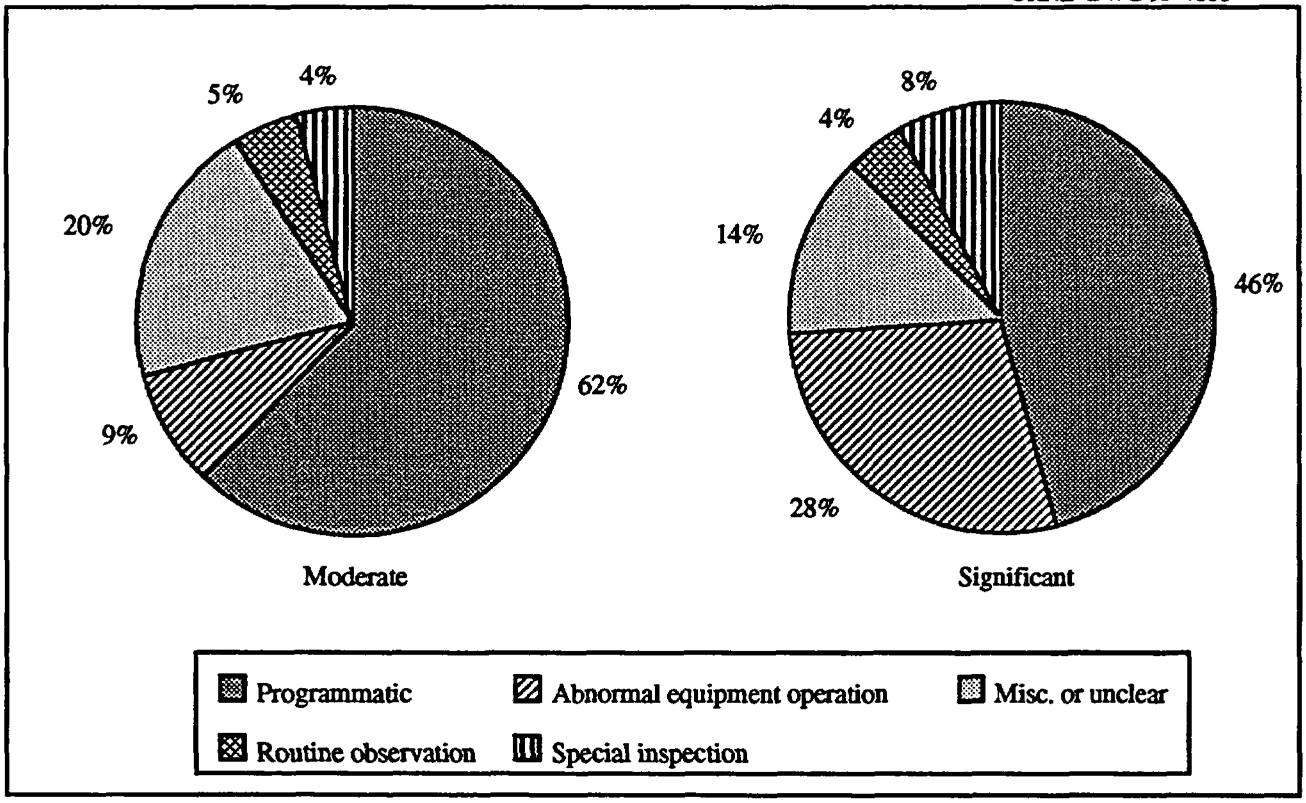


Figure 3.48 Distribution of failures by general detection method and extent of degradation

ORNL-DWG 93-7334

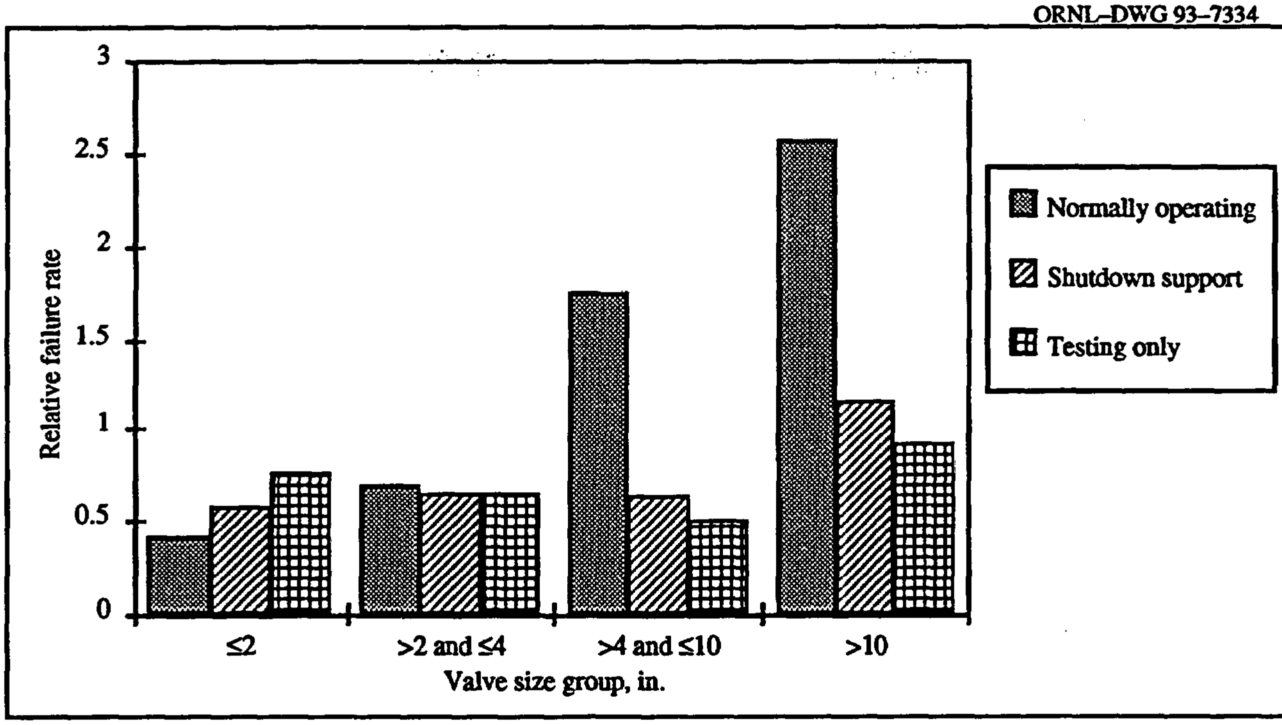


Figure 3.49 Relative failure rate by valve size group and system usage for failures classified as *Significant*

3.14 Results of Selected Plant Review

In order to provide a measure of inaccuracies in the ORNL characterization of the failures, failure narratives and characterizations for seven plants (12 units) were reviewed by plant personnel, using the related maintenance work order packages. ORNL was present during one of the reviews, and subsequently, with the help of NIC personnel, reviewed and tabulated the results. Two specific characterizations were tabulated: extent of degradation and failure area. Other parameters were also discussed, but a measure of accuracy for these two parameters was particularly sought. Tables 3.2 and 3.3 summarize the results of the plant specific review. Note that the sum of the net changes shown in table 3.3 do not equal zero, since some failures affect multiple areas.

Table 3.2 Summary of results of plant review of ORNL characterizations

Plant	Failures reviewed	Failure area changes	Extent of degradation changes	Comments
A	13	1	2	Both changes in extent went from moderate to significant
B	11	3	0	
C	16	5	2	Both changes in extent went from significant to moderate
D	6	2	0	
E	19	6	1 (marginal)	Extent change, if made, would be from significant to moderate
F	10	5	0	
G	16	2	2	Both changes in extent went from significant to moderate
Total	91	24	6 (plus one marg.)	Net change of 2 to 3% in the direction of reduced significance

Table 3.3 Summary of failure area plant review

Affected area:	Hinge pin	Disk stud/ hinge arm	Seat	Penetration	General wear	Dirt/foreign material	Unknown
Number failures in which area was deemed affected by the ORNL characterization	23	17	28	1	14	11	15
Net changes suggested by plant personnel	2	4	-2	1	-2	4	-4
Percentage change	9	24	-7	100	-14	36	-27

Note that there were initially a substantial number of extent of degradation characterizations to which plant personnel took exception (mostly where the plant personnel felt the assignment should have been *Moderate* instead of *Significant*). During subsequent follow-up review with NIC personnel, however, it became evident that almost all of the exceptions were due to the plant personnel having considered the degradation in safety for the *system* or *plant* rather than the extent of *valve* degradation. The figures in Table 3.2 reflect the results of the follow-up review.

These results suggest that the extent of degradation cross-correlation results should be relatively accurate, but the results associated with failure area characterizations should be viewed with some suspicion.

Two obvious limitations of the characterizations are (1) the accuracy and thoroughness of the narratives and (2) the ability of the reviewer to correctly interpret the narratives. During the course of the review, it became very clear that utilities have substantially improved the length and quality of narratives submitted to the NPRDS data base during recent years. To check the validity of this observation, the average length of text in the narratives for failures occurring in the years 1984-1990 was calculated. The results are shown in Figure 3.50.

ORNL–DWG 93–7335

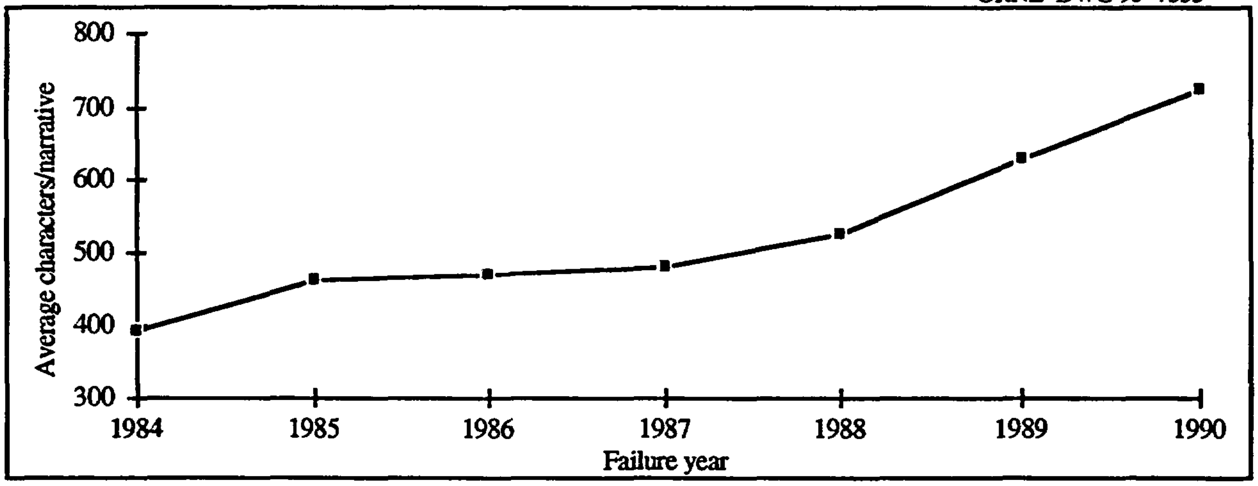


Figure 3.50 Average text length for check valve failure narratives characterized vs failure year

With the additional length of narratives, there also appeared to be a trend toward higher quality, though this was not quantifiable. It can be concluded that the thoroughness of the narratives is improving, thereby paving the way for improvements in the quality of reviews of the nature of this study in the future. However, to address the second area of limitation noted above, it would greatly enhance the ease of use and accuracy of the data base if means were provided to directly code in parameters such as the affected area of the valve. Alternatively, if utility personnel who are responsible for submitting the failure records were made aware of the need to include such information in the narratives, the information could be obtained indirectly (and with more difficulty).

Discussions with NIC personnel resulted in the identification of the desirability of exploring possible changes in either the NPRDS data base itself, or in the reporting practices within the existing structure. NIC indicated that they will pursue this independently.

4 Summary, Conclusions, and Recommendations

4.1 Summary

This study was conducted to identify failure patterns associated with check valves used in nuclear power plants in the U.S during the years 1984-1990. The source of data for the study was the NPRDS database. The failure data from the database was filtered to remove those failures that involved external leakage as well as those that clearly involved only minor internal leakage.

In order to provide results that were not biased by population sizes, the data was normalized to the relevant population group. A "relative failure rate" was developed for the design and failure characteristic parameters evaluated. This relative failure rate, along with other measures, was used to develop and present the data in a normalized fashion.

The study found some parameters that yielded relatively strong failure trends, while there were no apparent trends or correlations for other characterized parameters.

There was minimal relationship found between failure rate and valve or plant age.

Large valves were found to be more likely to degrade and more likely to degrade significantly than smaller valve sizes. This relationship was particular true for valves used in systems that are normally operating. Valves that are greater than 10 in. and used in normally operating systems were twice as likely to fail as the valve population as a whole.

Valves used in service water, main steam, feedwater, and diesel starting air systems were found to be two or more times as likely to fail as the valve population as a whole. However, the diesel starting air system valve failures were, on the average, less extensively degraded than were the valves in these other three systems.

Significant differences in failure rates by manufacturer were found. Factors such as the severity of duty for specific valve applications, which were beyond the scope of this study, likely had a significant impact on these rates.

BWR plants had a higher overall relative failure rates; however, this was clearly the result of the fact that BWR plants are better structured to detect failures programmatically; failure rates for all detection means other than programmatic were lower for BWRs than for PWRs.

Valves used in systems that are normally in service did not experience significantly higher failure rates overall than did valves used in infrequently used systems (used in support of shutdown operations or for testing only). However, as noted above, the failure rate for valves used in normally operating systems had a strong relationship to valve size. In addition, valves used in normally operating systems were about twice as likely to fail stuck open as those not normally in use. On the other hand, valves used in systems used only during testing were more likely to stick shut.

Degradation of the disk stud and/or hinge arm area was the least likely area to be detected programmatically; failures in this area were also among the most significant in extent of degradation.

4.2 Conclusions

This study has shown that failure rates for check valves are clearly related to certain characteristics and features. Specific plant and system features which are beyond the scope of this study are also influential in degradation and failure rate; thus, the results presented herein should be considered as only part of the picture.

These analysis results may be useful to those seeking to optimize the use of resources. The results may also be useful as baseline information for several types of comparisons, such as individual plant experience with that of the industry as a whole, and trending industry performance with time. The latter may be particularly pertinent during the next few years, to determine how successful advances in monitoring techniques and programmatic controls are in improving valve reliability.

4.3 Recommendations

It is recommended that periodic updates of this study be performed to provide an indication of industry trends. It is further recommended that, to the extent feasible, additional parameters be considered in future reviews, either as a part of the periodic update process or as a separate review. Parameters that merit consideration include:

- valve type (swing, lift, tilting disk, dual disk, etc.),
- valve orientation (horizontal, vertical, distance from upstream disturbances, etc.), and
- monitoring or maintenance programs for specific valves (such as IST).

Reference

1. M. L. Scott, "Check Valve Failure Trends in the Nuclear Industry," EPRI Power Plant Valves Symposium II, Charlotte, N.C., July 1989. Available for purchase from the Research Reports Center, Box 50490, Palo Alto, CA 94303.

Appendix

Charts of Study Results

ORNL-DWG 93-7336

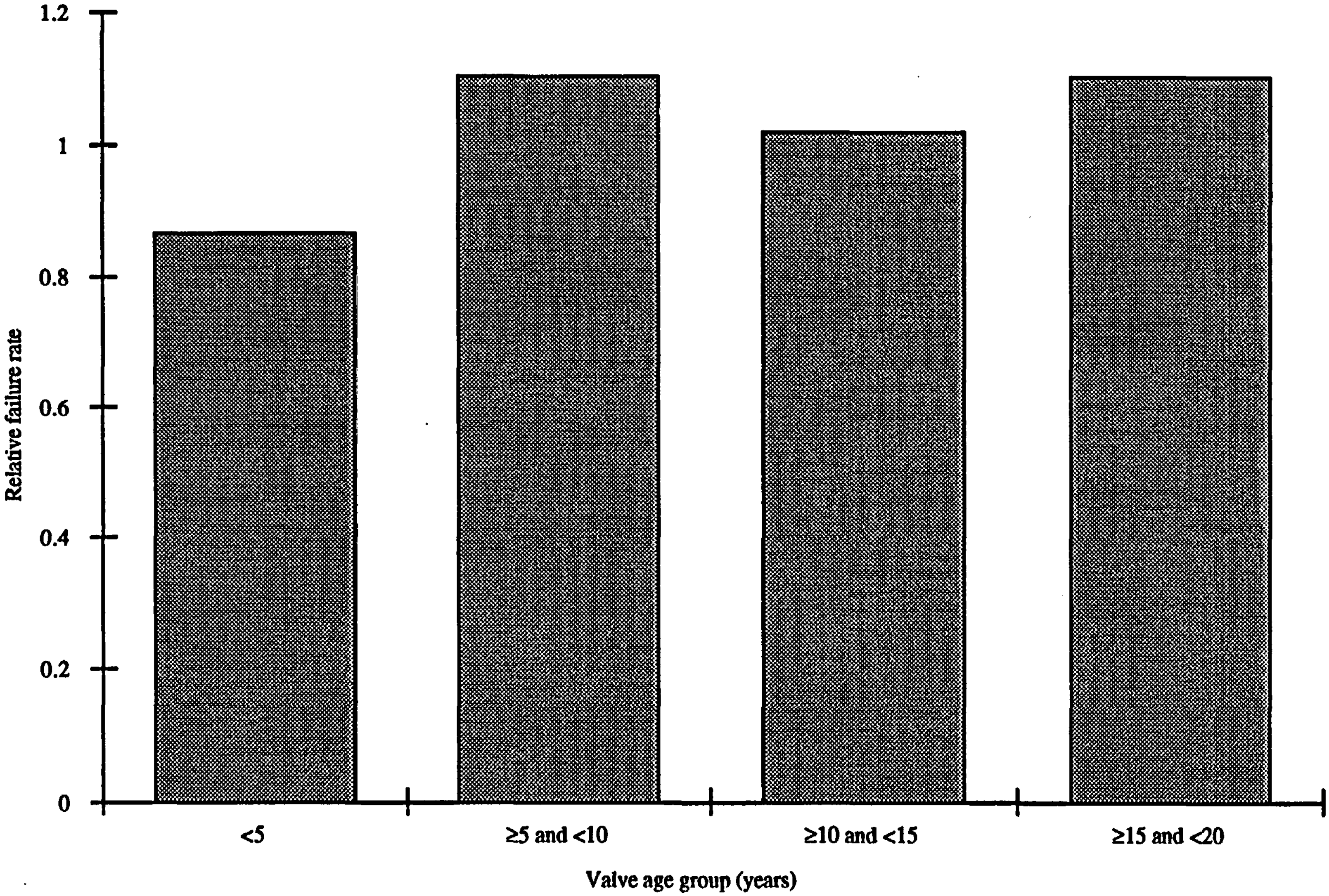


Figure A.1.1 Relative failure rate by valve age group

ORNL-DWG 93-7337

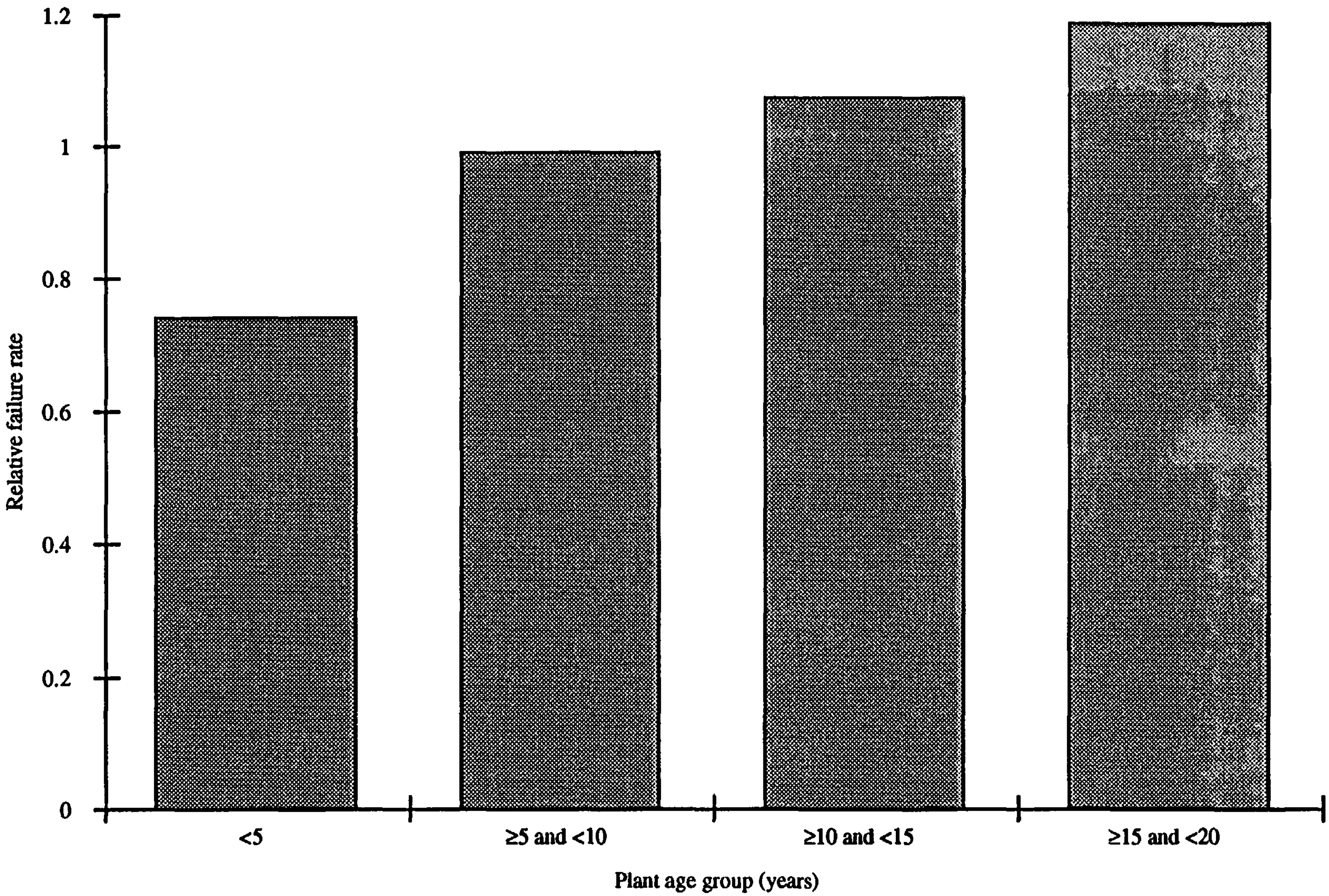


Figure A.1.2 Relative failure rate by plant age group

ORNL-DWG 93-7338

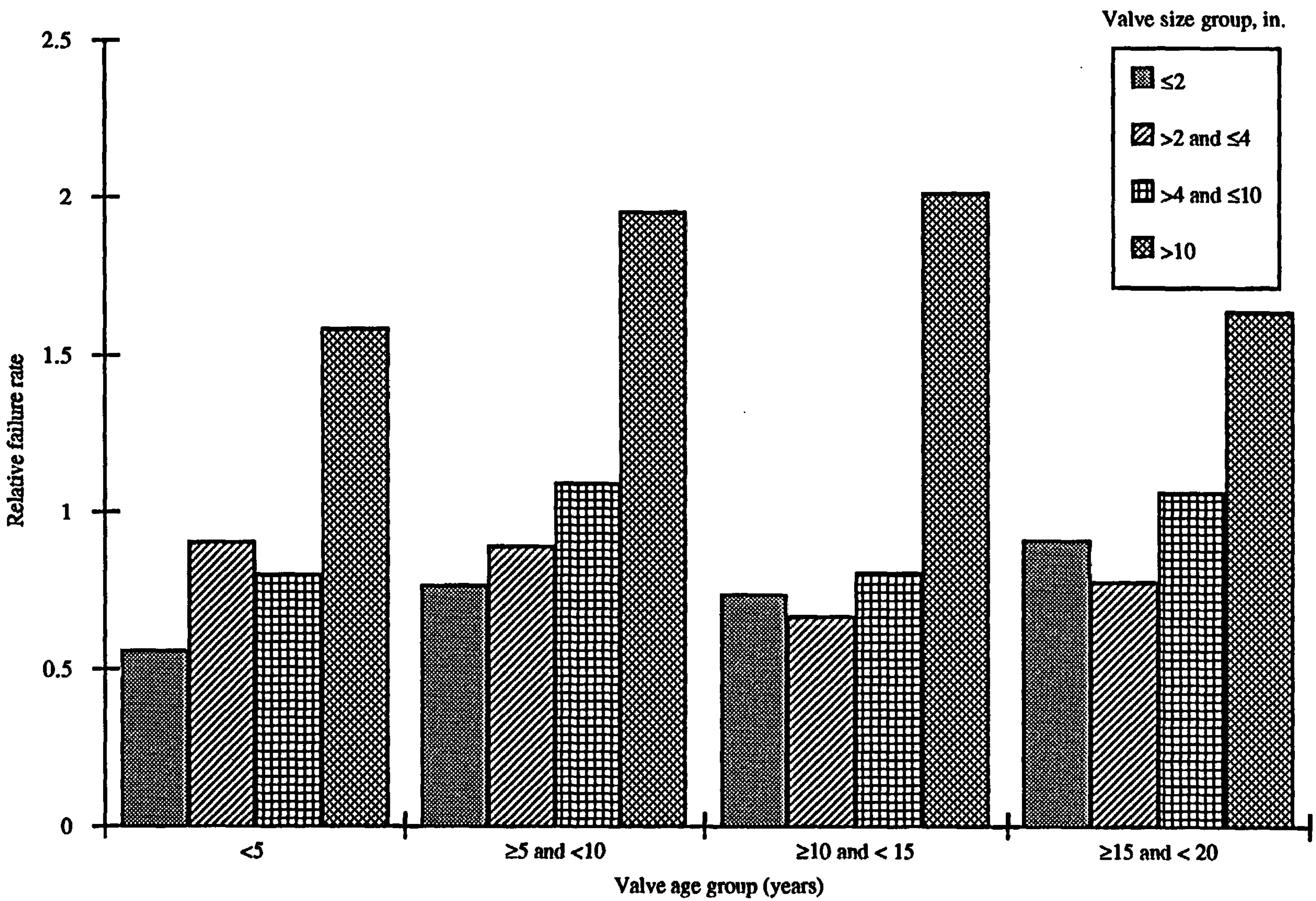


Figure A.1.3 Relative failure rate by valve age group and valve size group

ORNL-DWG 93-7339

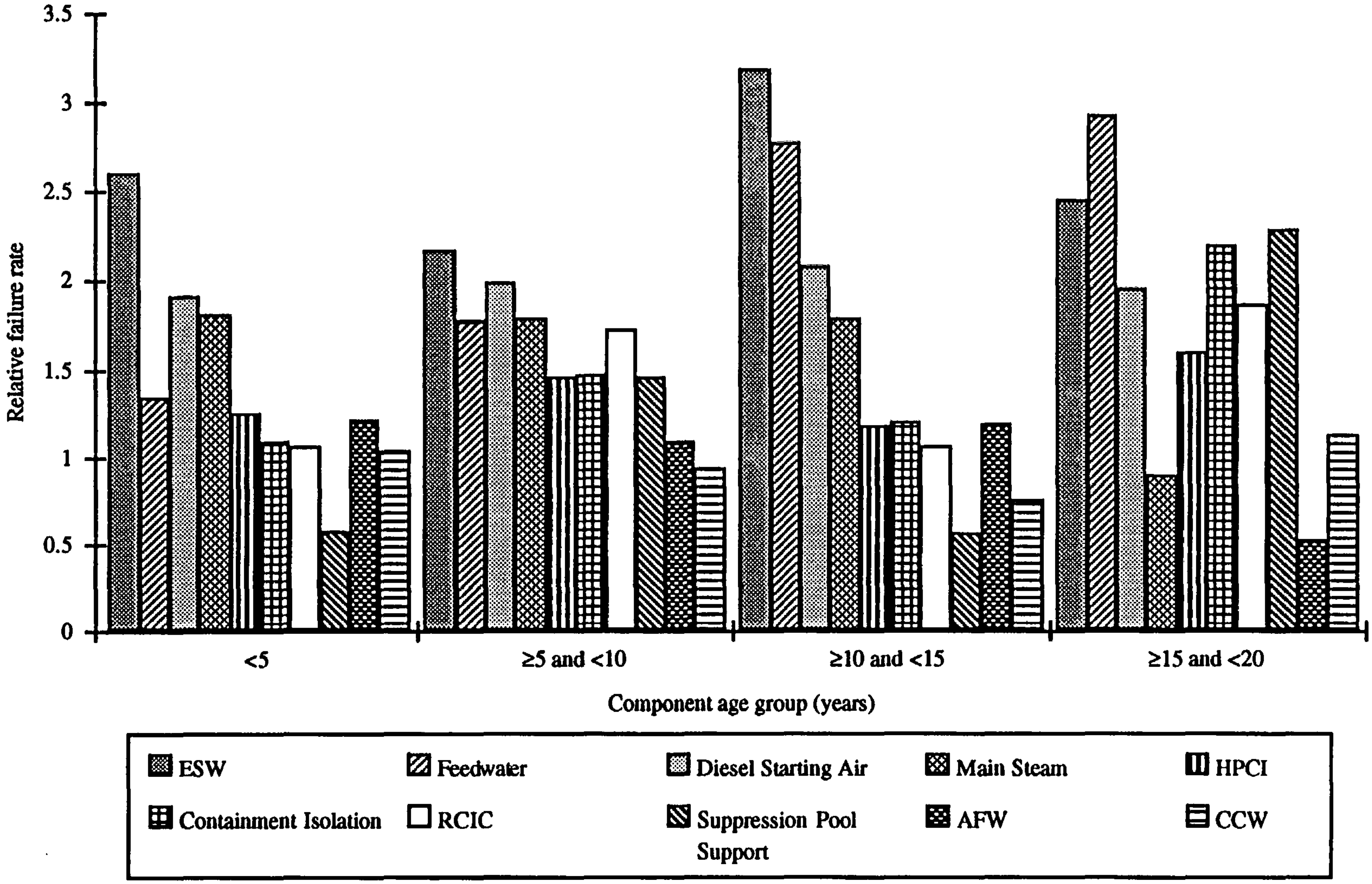


Figure A.1.4 Relative failure rate by valve age group and system for ten systems with the highest overall relative failure rate

ORNL-DWG 93-7340

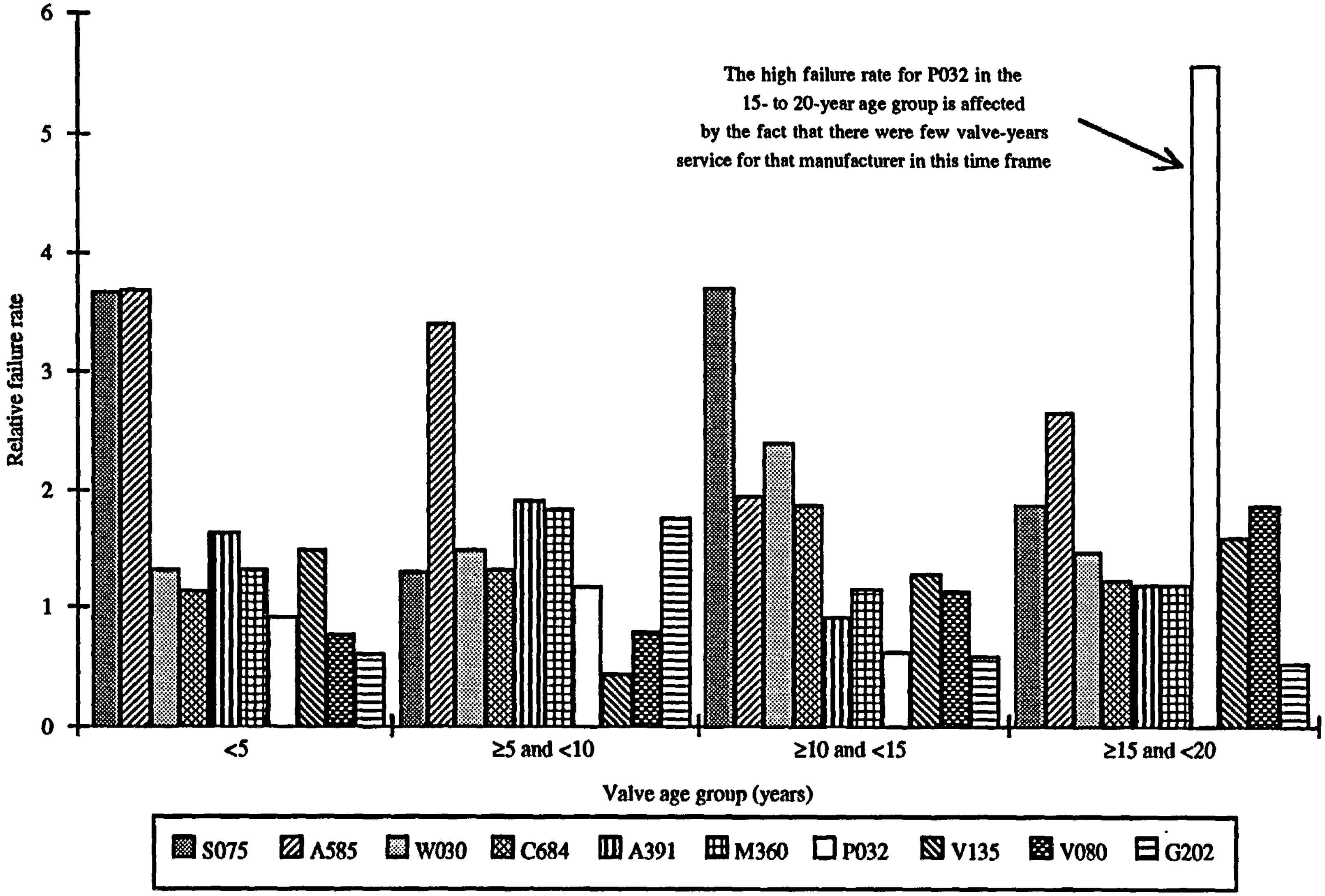


Figure A.1.5 Relative failure rate by valve age group and manufacturer for ten manufacturers with the highest overall relative failure rate

ORNL–DWG 93–7341

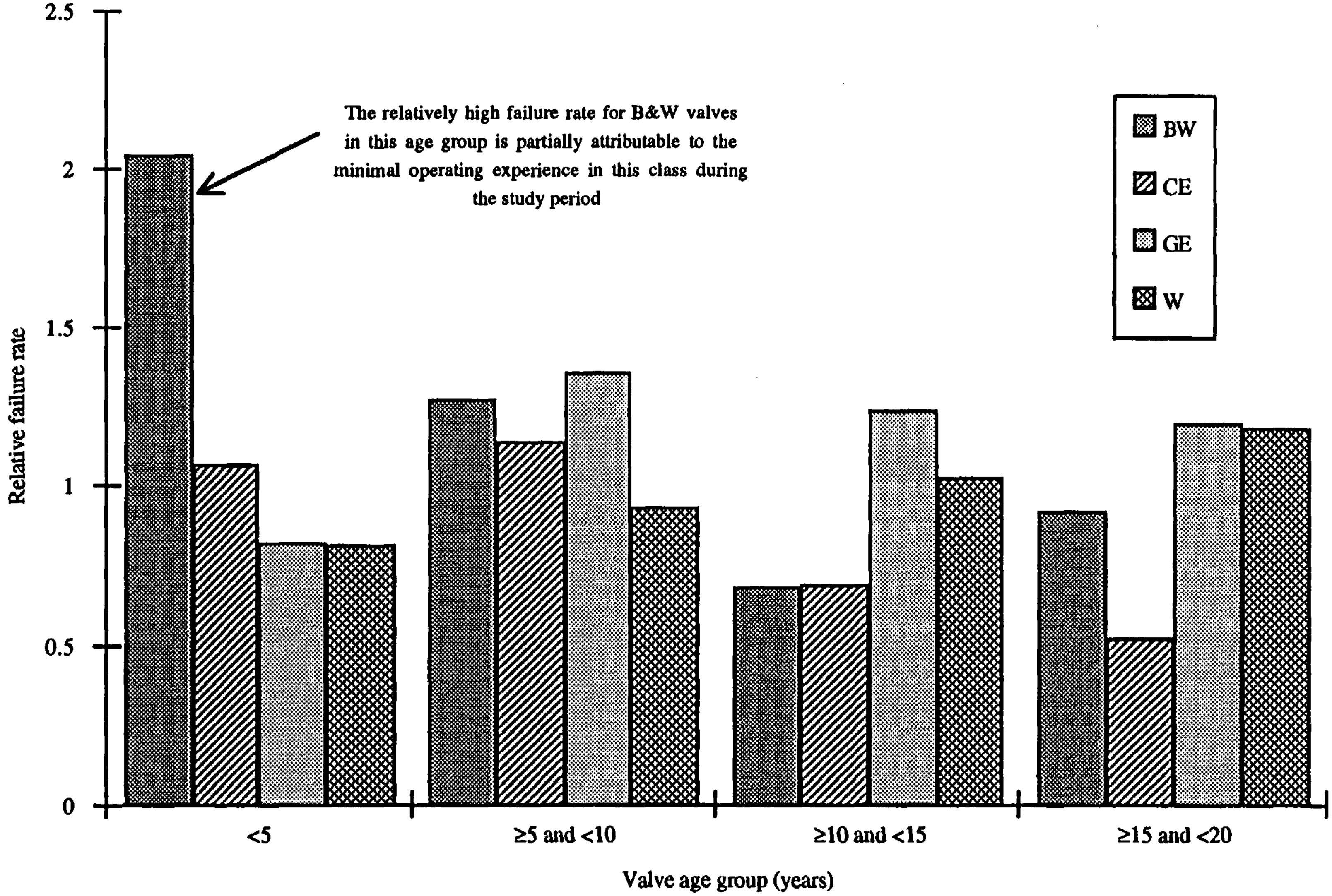


Figure A.1.6 Relative failure rate by valve age group and NSSS

ORNL–DWG 93–7342

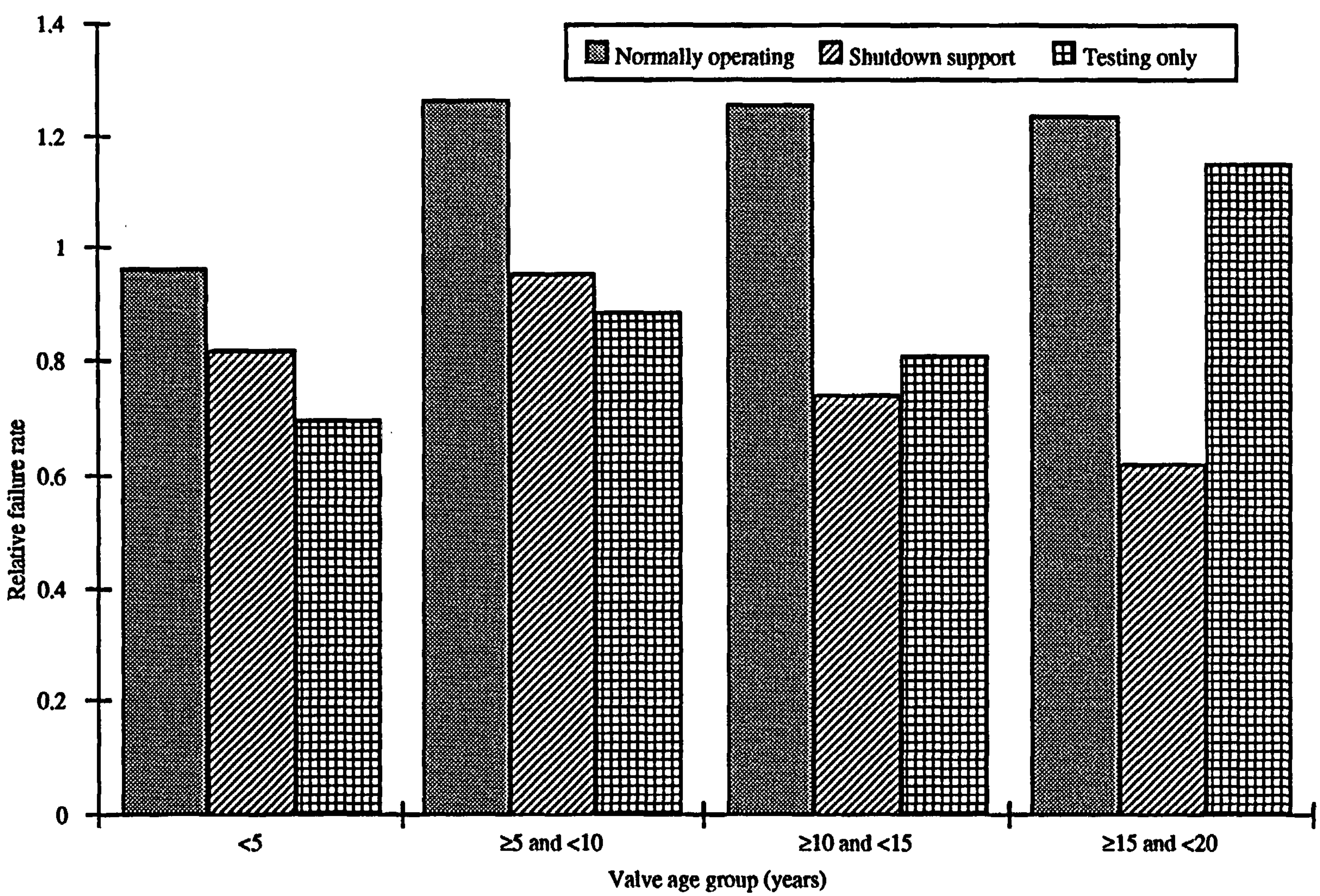


Figure A.1.7 Relative failure rate by valve age group and system usage

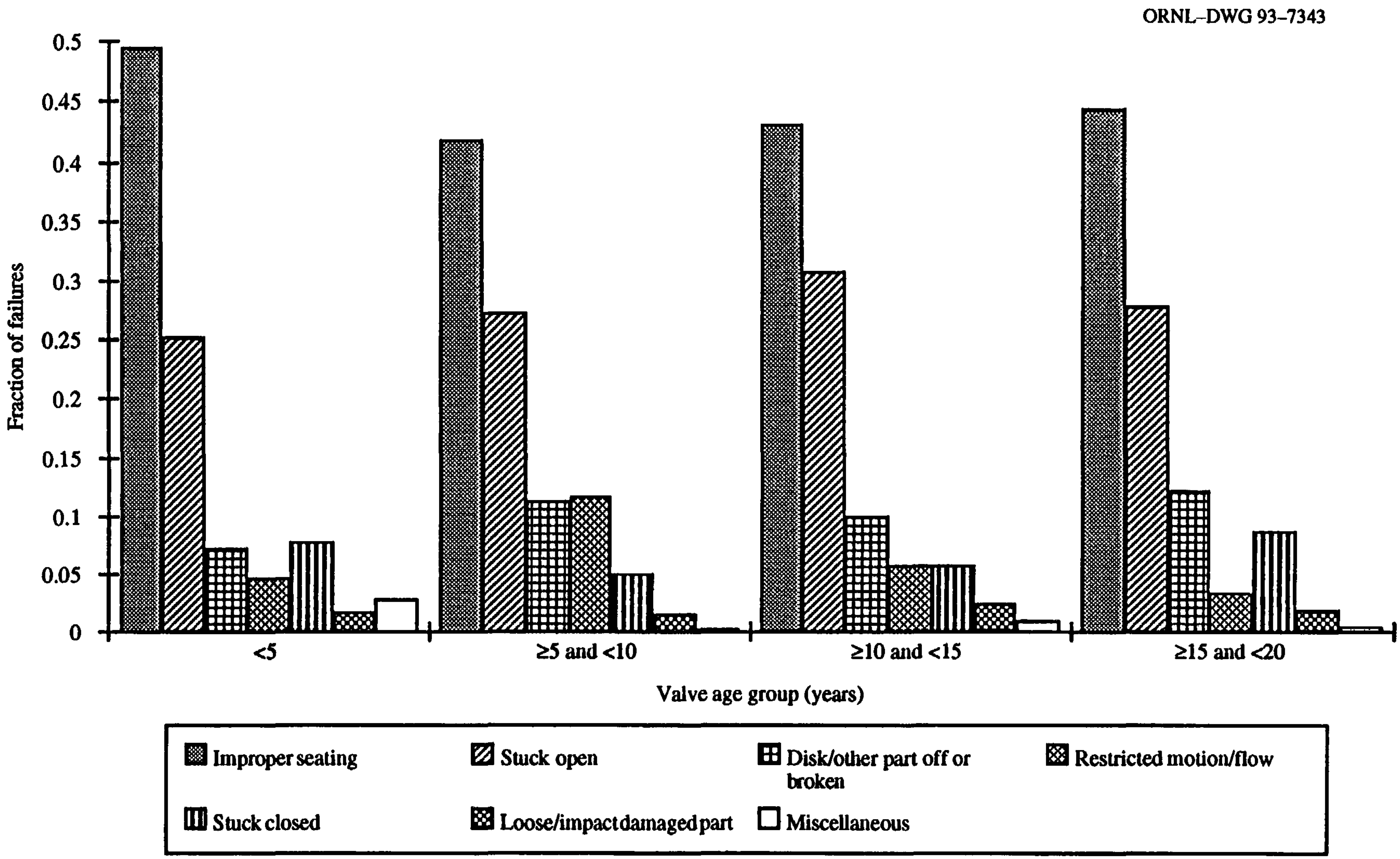


Figure A.1.8 Distribution of failures by age and failure mode

ORNL-DWG 93-7344

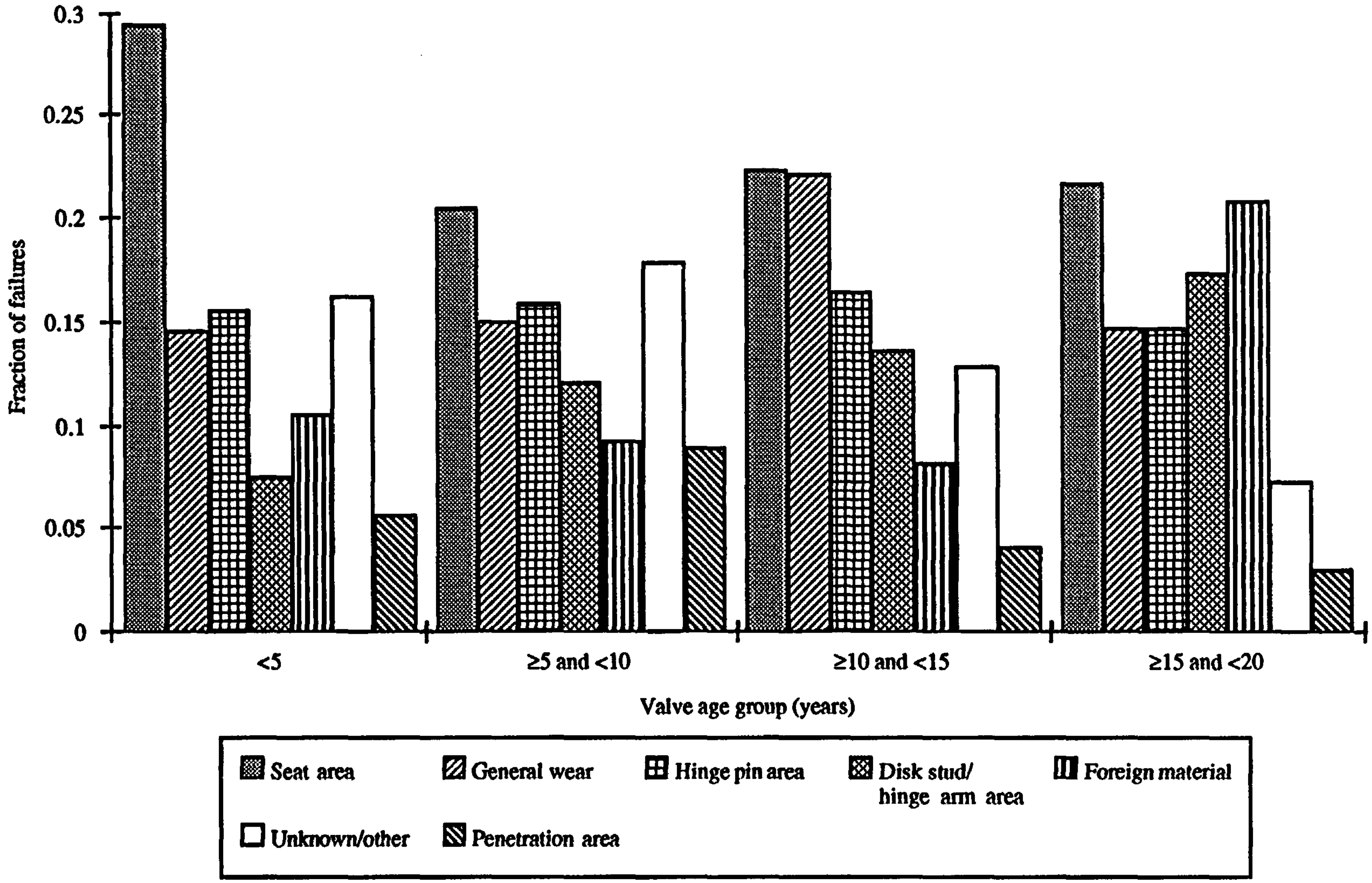


Figure A.1.9 Distribution of failures by valve age group and failure area

ORNL-DWG 93-7345

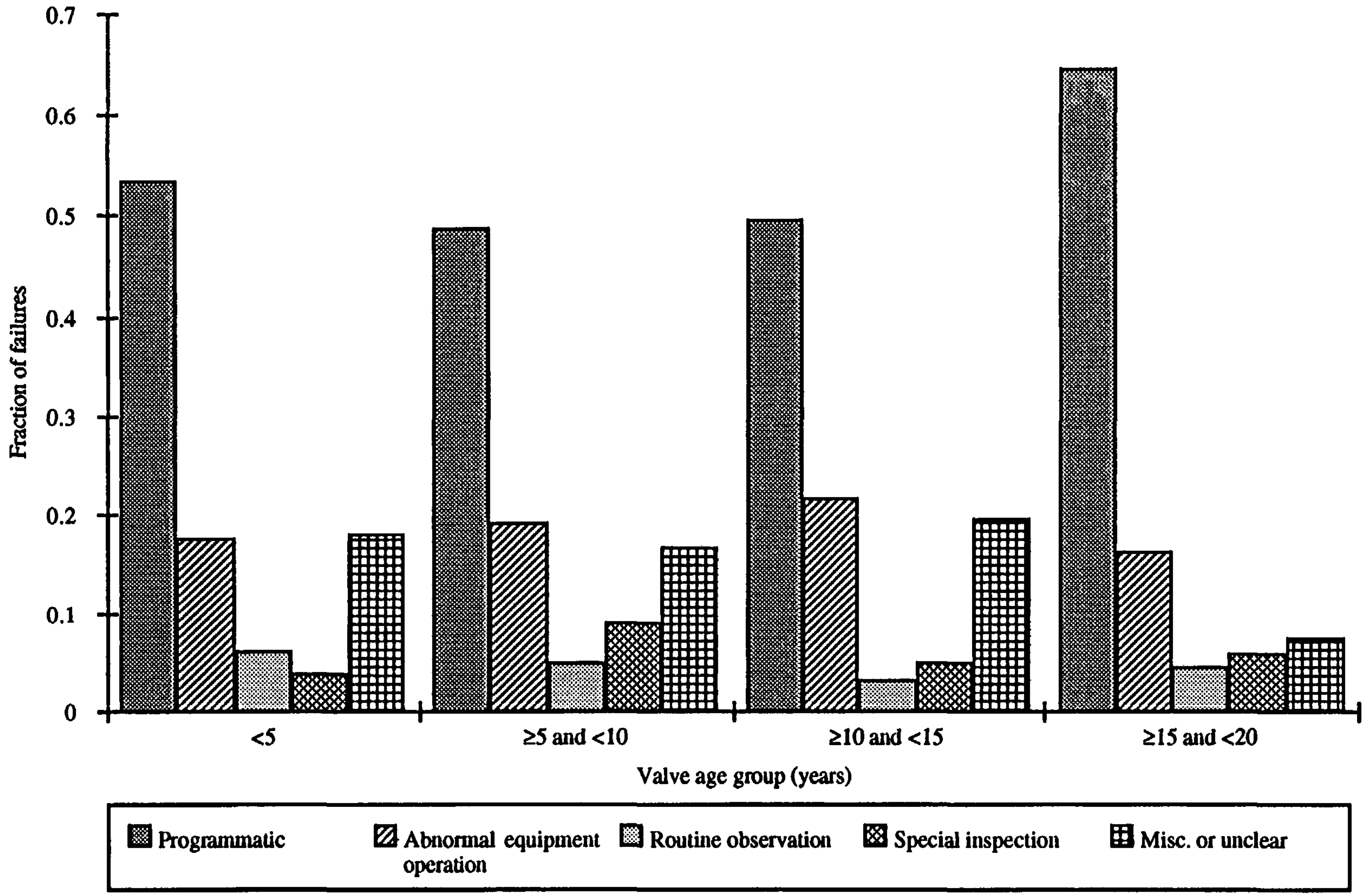


Figure A.1.10 Distribution of failures by valve age group and general discovery method

ORNL-DWG 93-7346

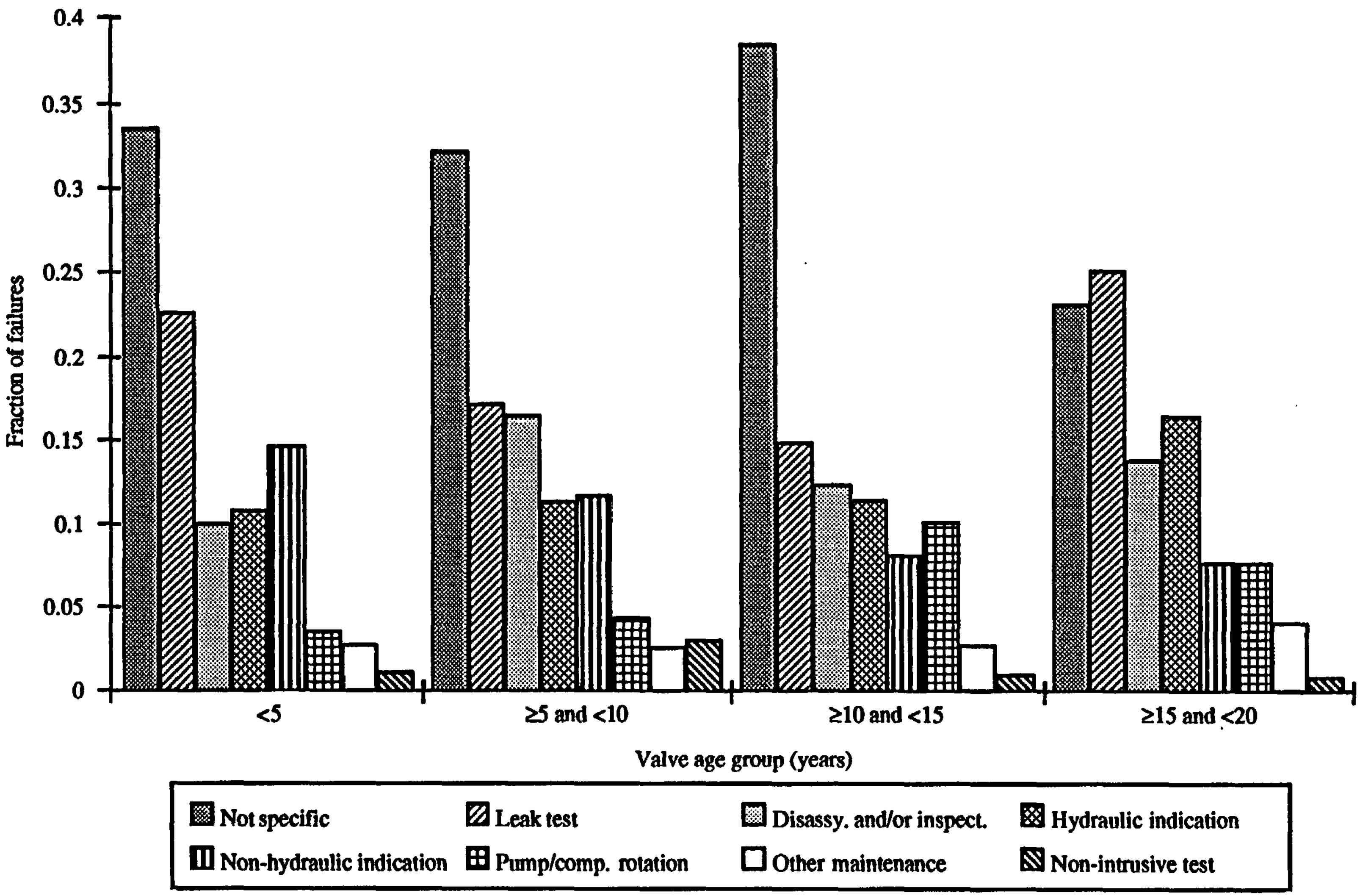


Figure A.1.11 Distribution of failures by valve age group and specific discovery method

ORNL-DWG 93-7347

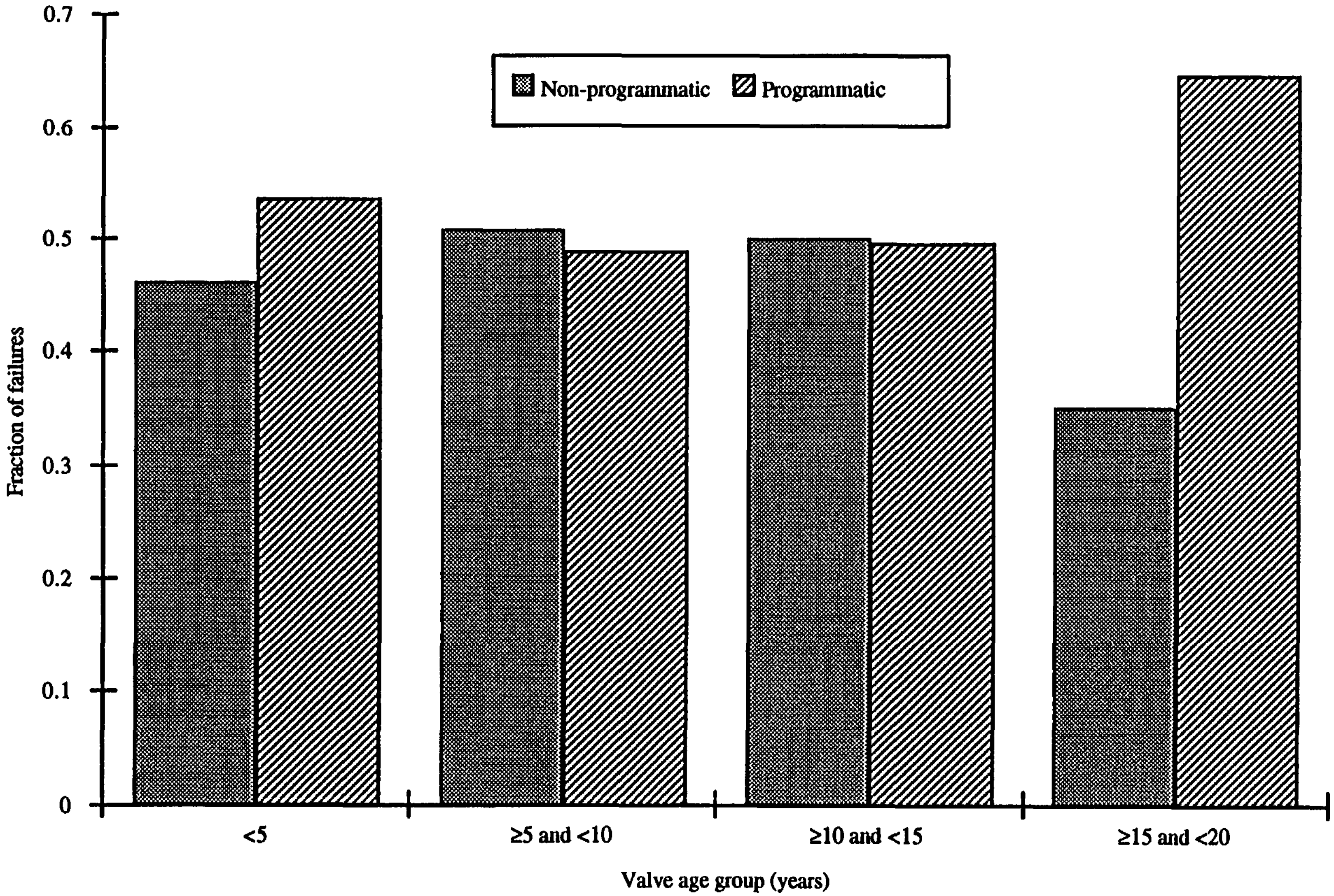


Figure A.1.12 Distribution of failures by valve age group and discovery process

ORNL-DWG 93-7348

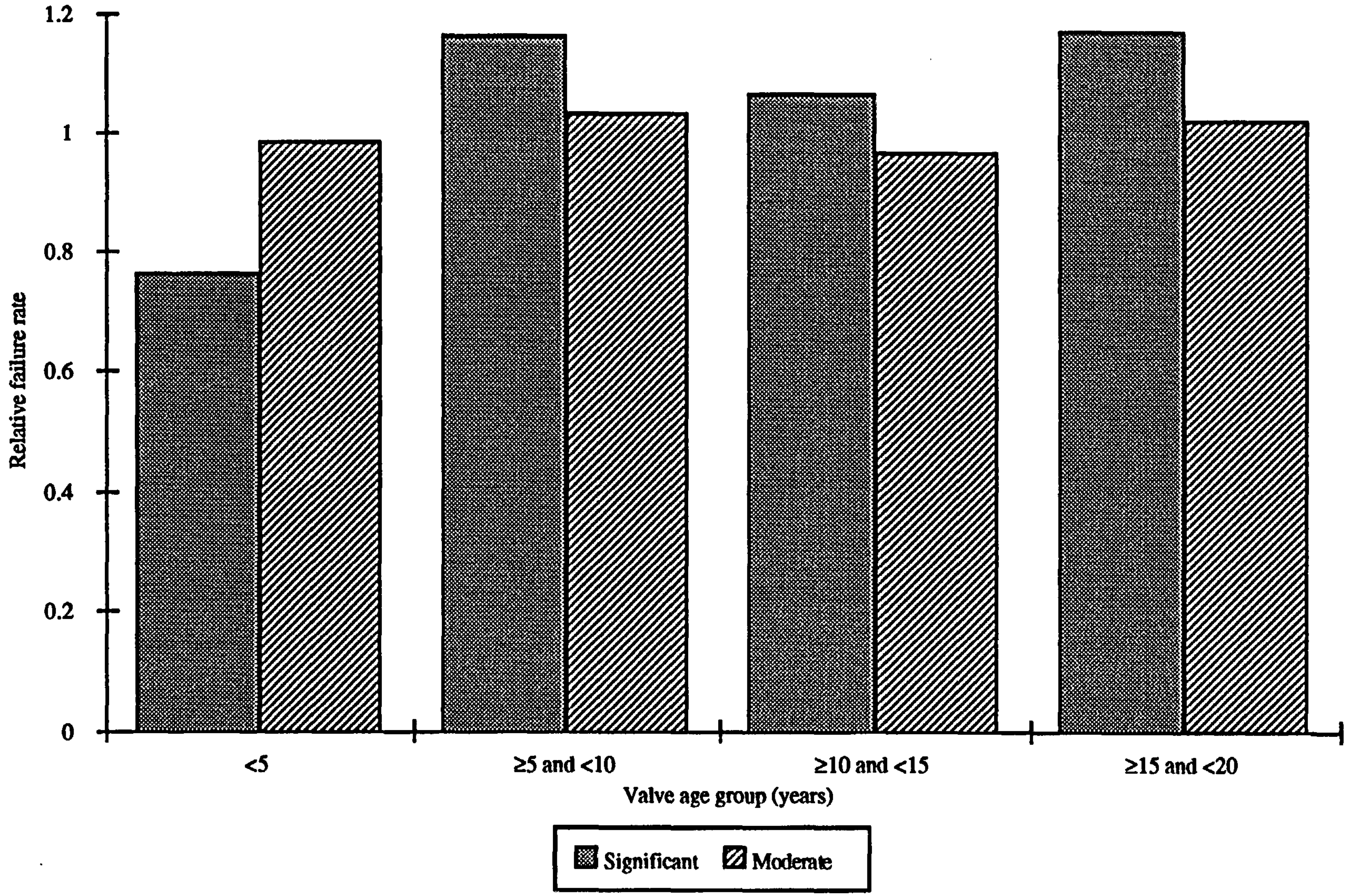


Figure A.1.13 Comparison of relative failure rates by valve age group and extent of degradation

ORNL–DWG 93–7349

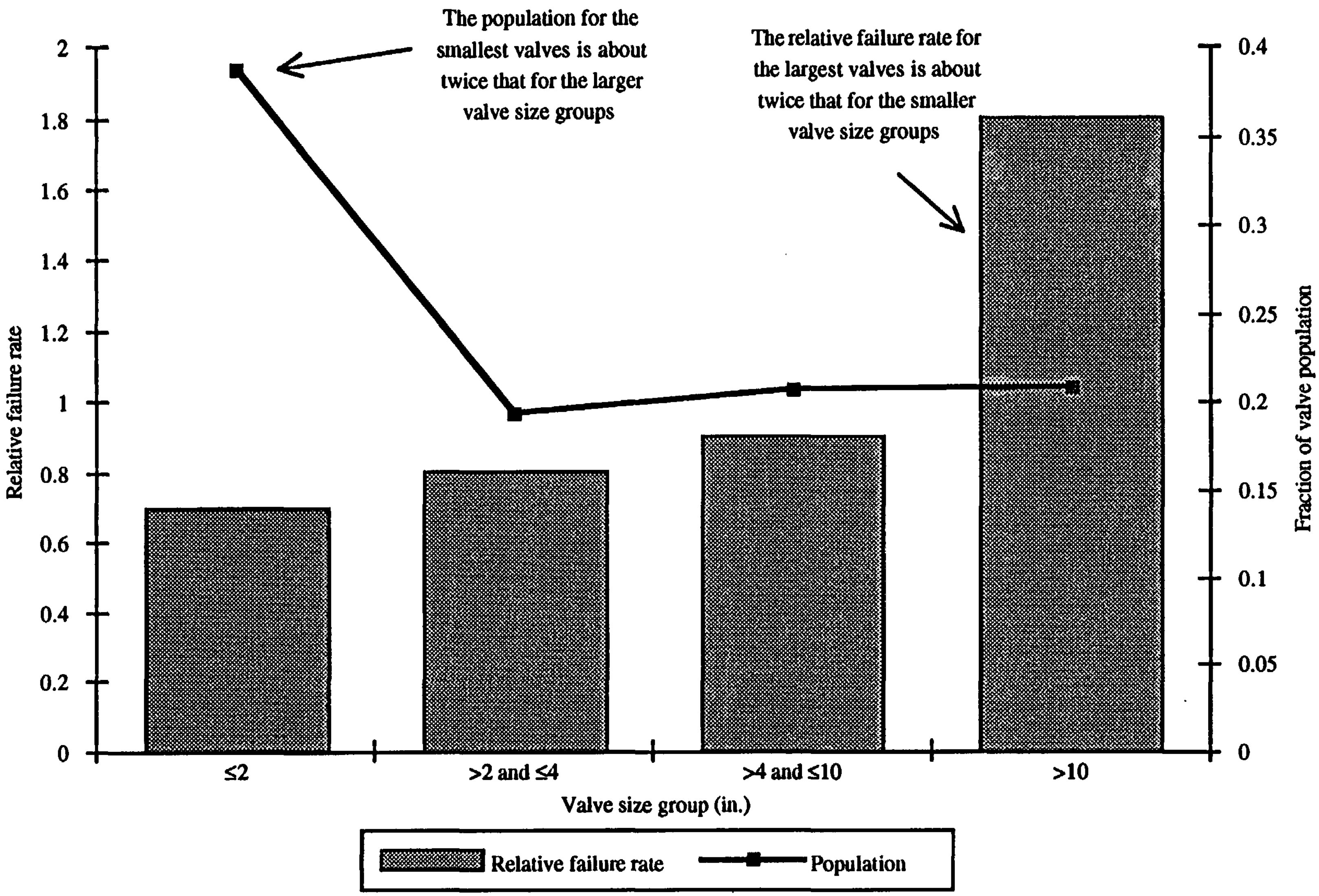


Figure A.2.1 Relative failure rate and population distribution by valve size group

ORNL–DWG 93–7350

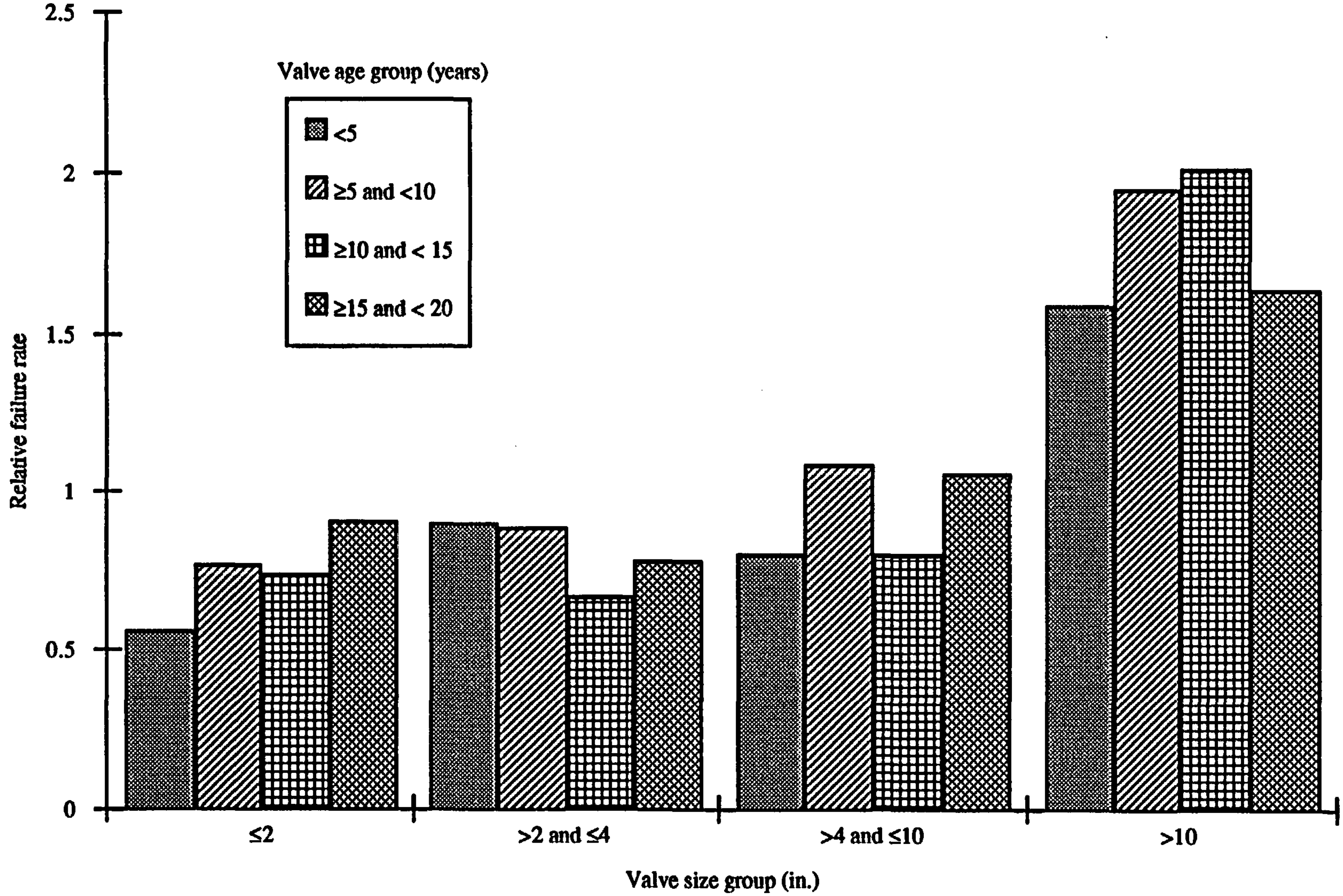


Figure A.2.2 Relative failure rate by valve size group and component age group

ORNL–DWG 93–7351

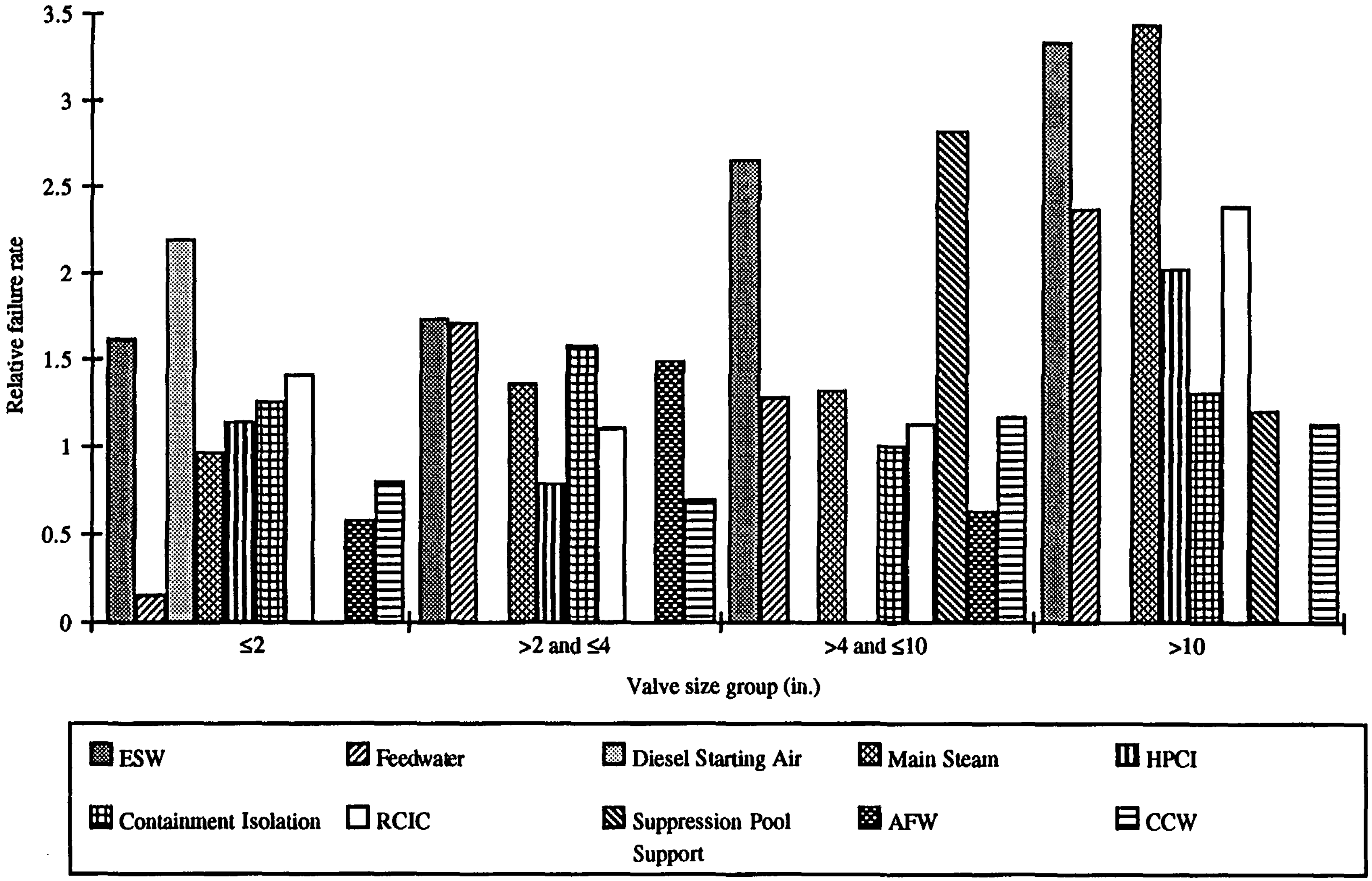


Figure A.2.3 Relative failure rate by valve size group and system

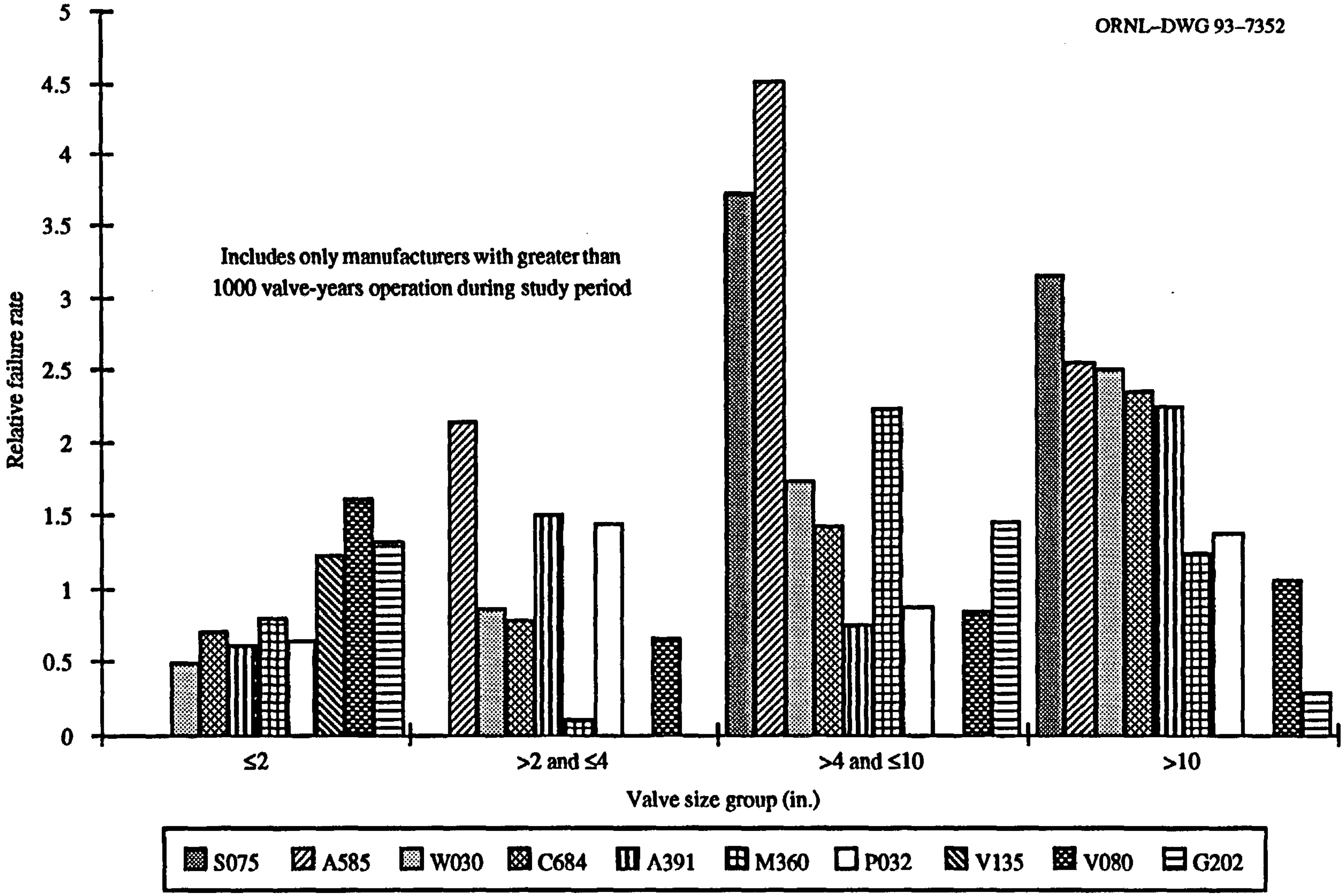


Figure A.2.4 Relative failure rate by valve size group and manufacturer for ten manufacturers with the highest overall relative failure rate

ORNL-DWG 93-7353

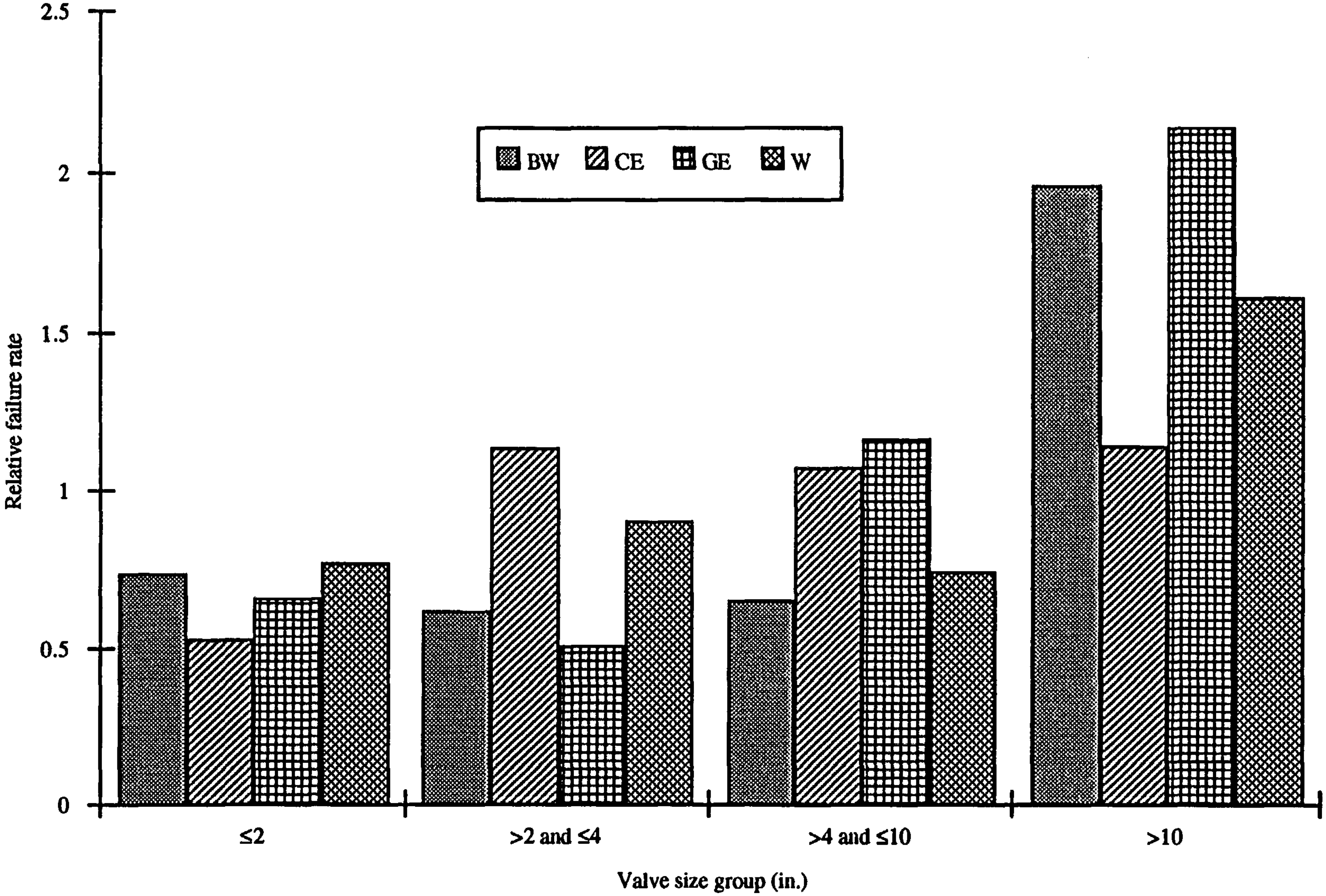


Figure A.2.5 Relative failure rate by valve size group and NSSS

ORNL-DWG 93-7354

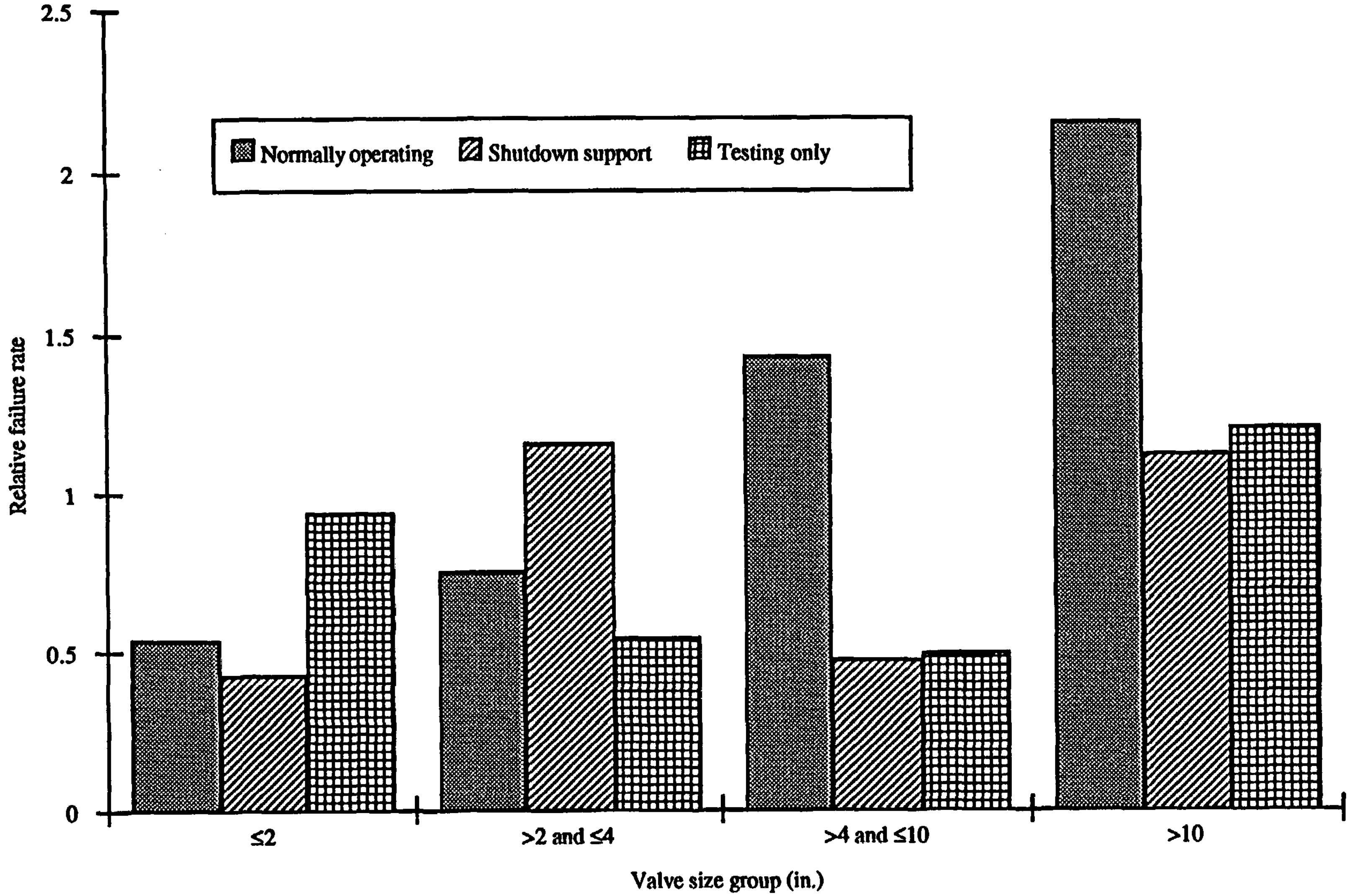


Figure A.2.6 Relative failure rate by valve size group and system usage

ORNL-DWG 93-7355

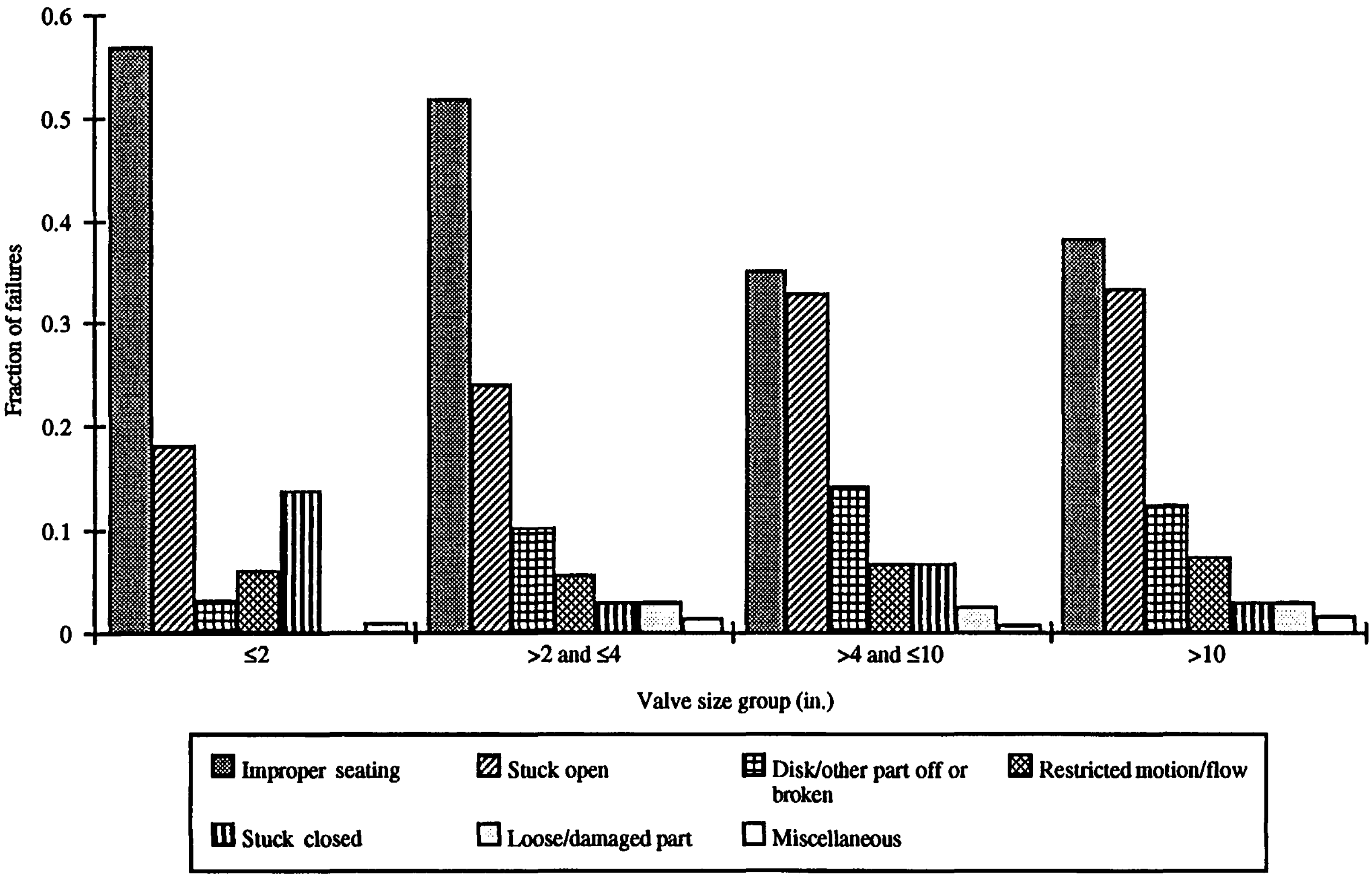


Figure A.2.7 Distribution of failures by valve size group and failure mode

ORNL-DWG 93-7356

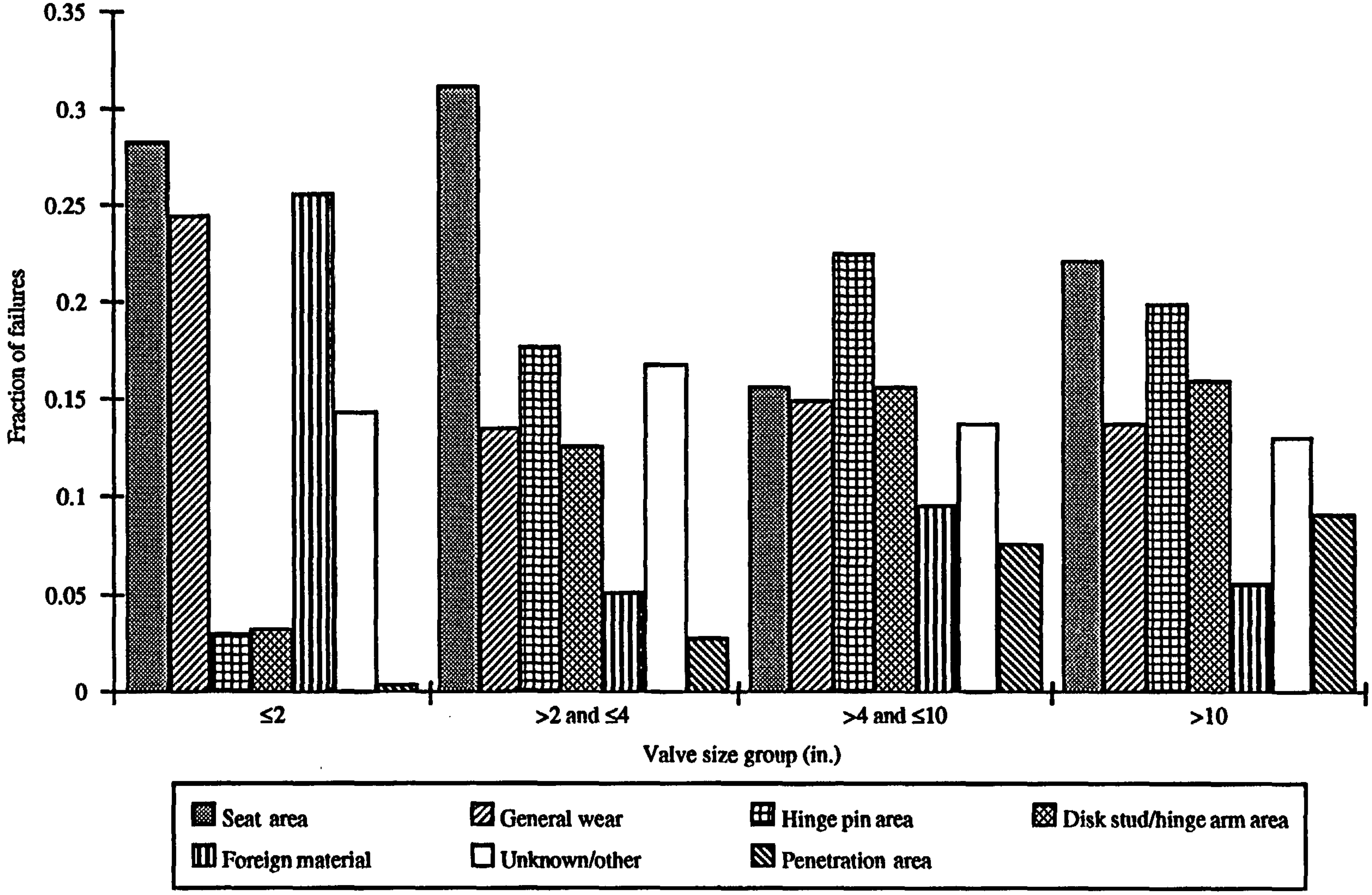


Figure A.2.8 Distribution of failures by valve size group and failure area. The values shown reflect the fraction of failures within the designated size group in which the specified area was affected. The sum of the values within each size group exceed one since some failures affected multiple areas

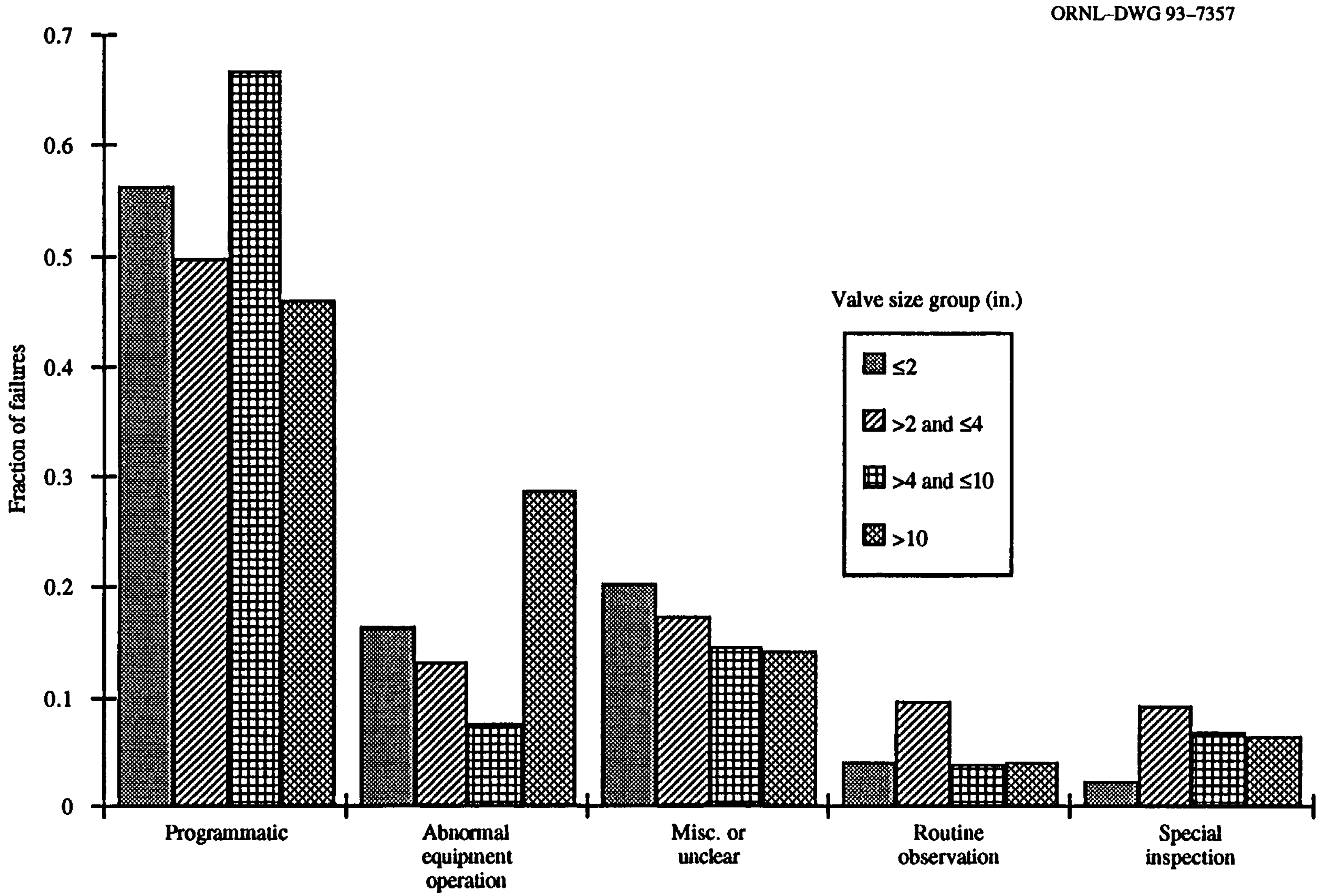


Figure A.2.9 Distribution of failures by valve size group and general detection method

ORNL-DWG 93-7358

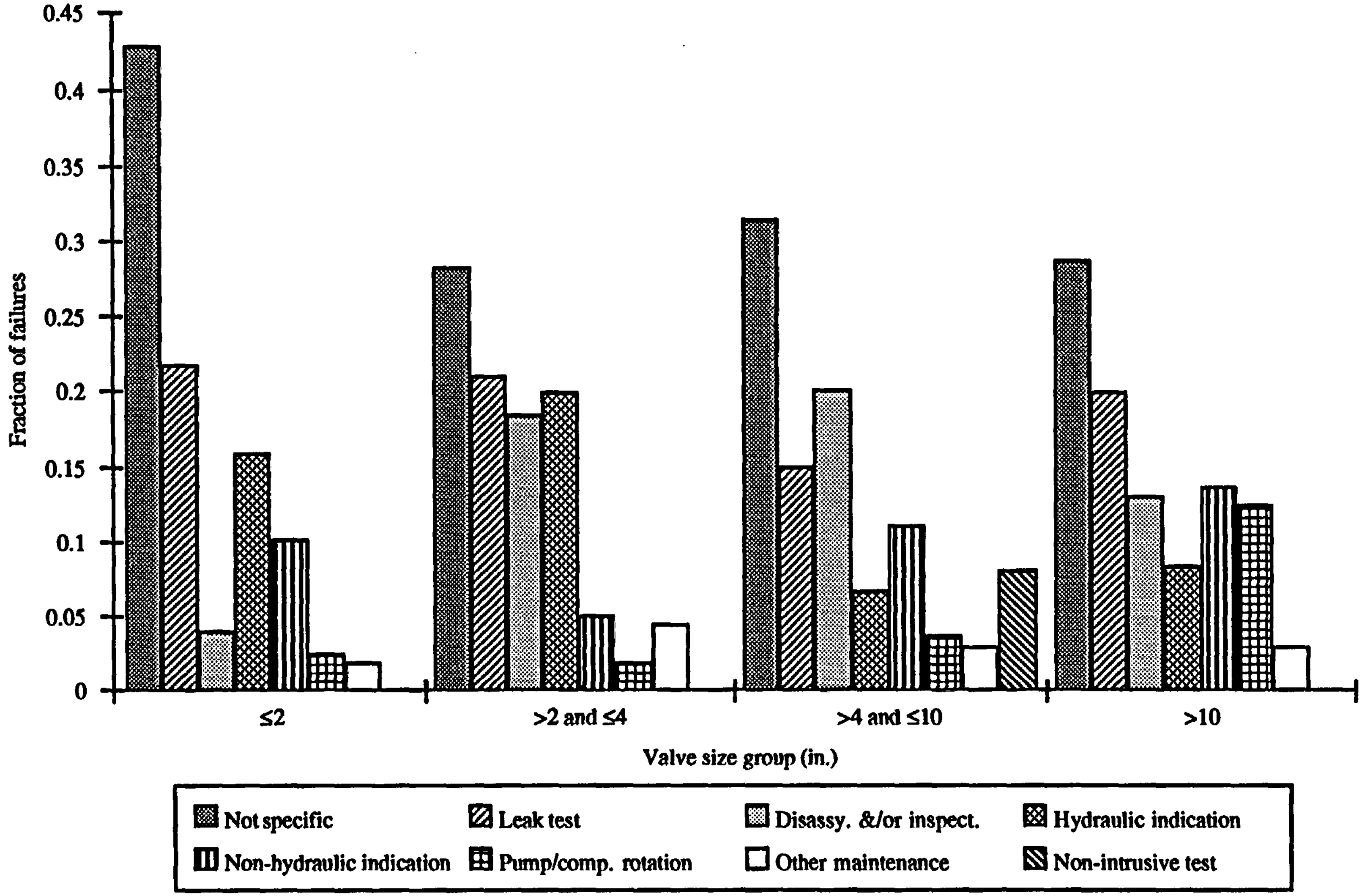


Figure A.2.10 Distribution of failures by valve size group and specific discovery method

ORNL–DWG 93–7359

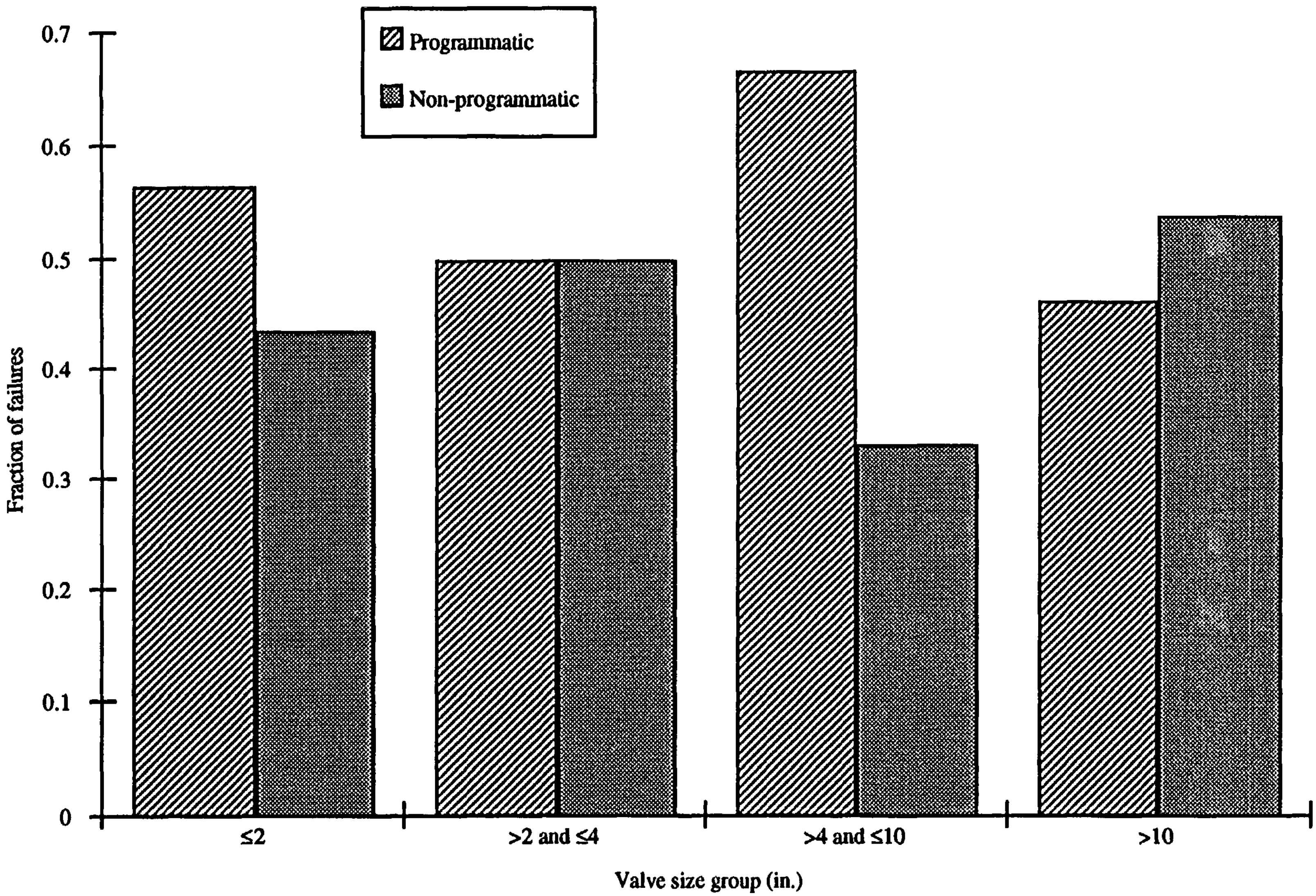


Figure A.2.11 Distribution of failures by valve size group and discovery process

ORNL-DWG 93-7360

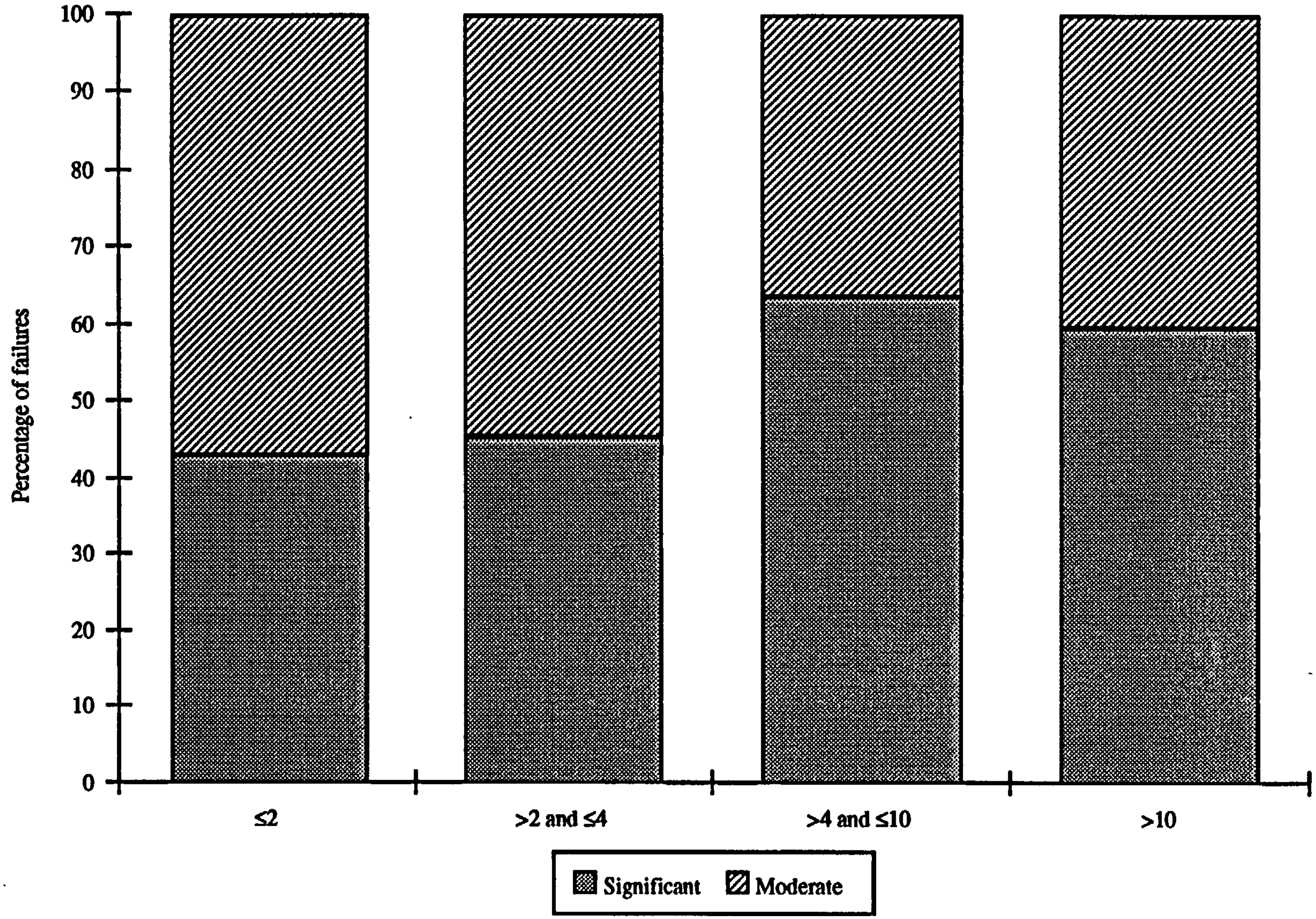


Figure A.2.12 Distribution of failures by valve size group and extent of degradation

ORNL-DWG 93-7361

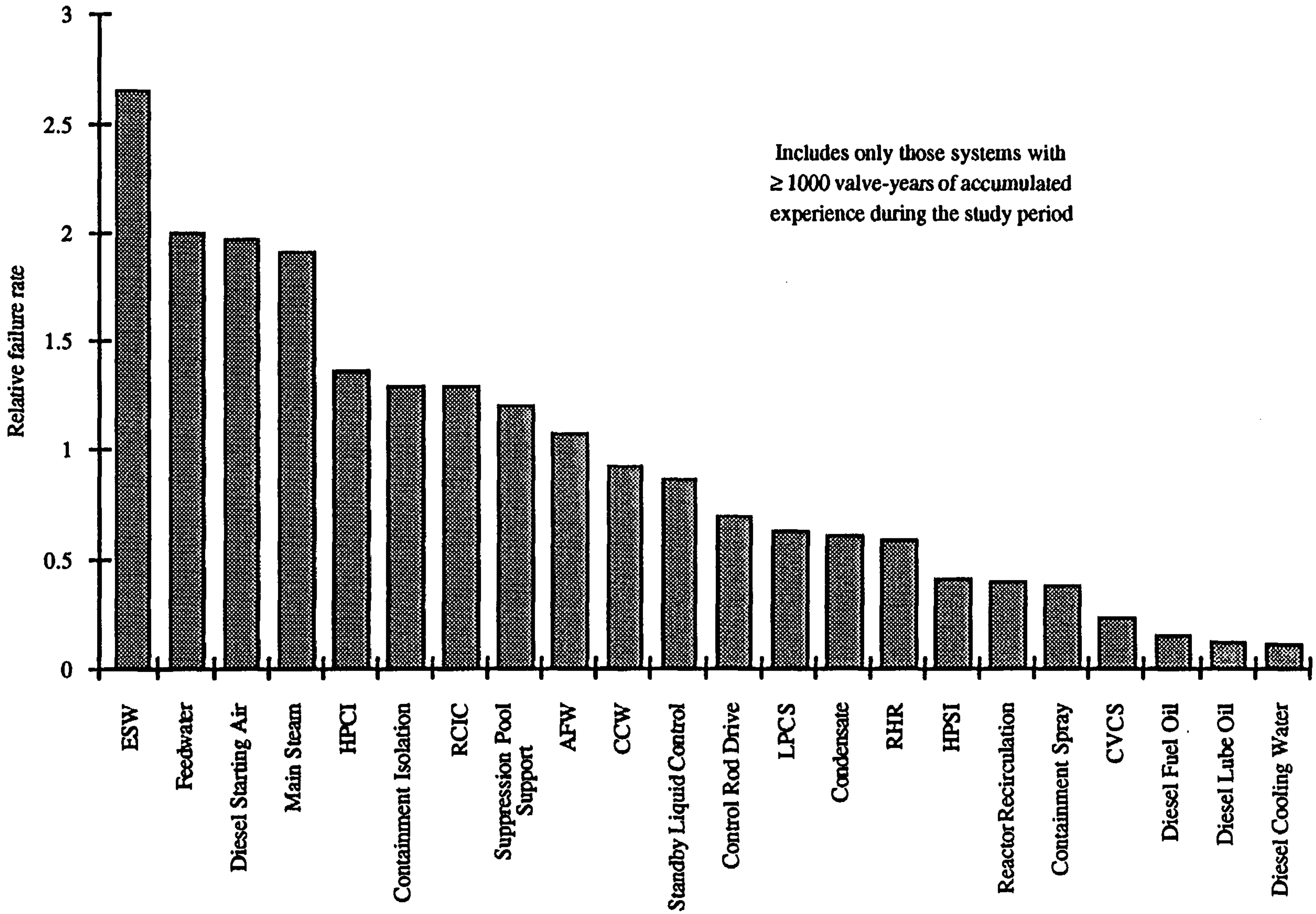


Figure A.3.1 Relative failure rate by system

ORNL-DWG 93-7362

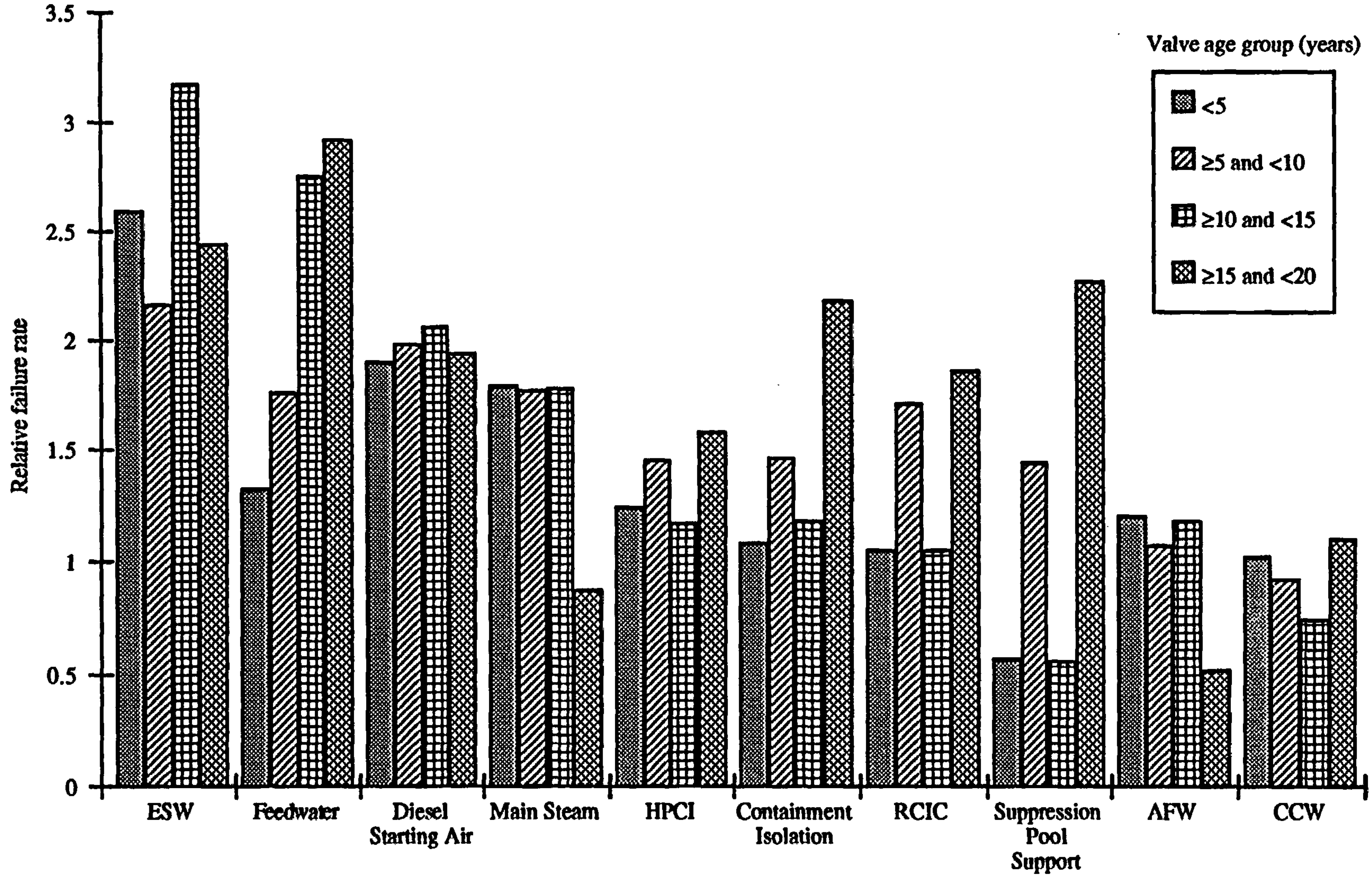


Figure A.3.2 Relative failure rate by system and component age group for ten systems with the highest overall failure rate

ORNL–DWG 93–7363

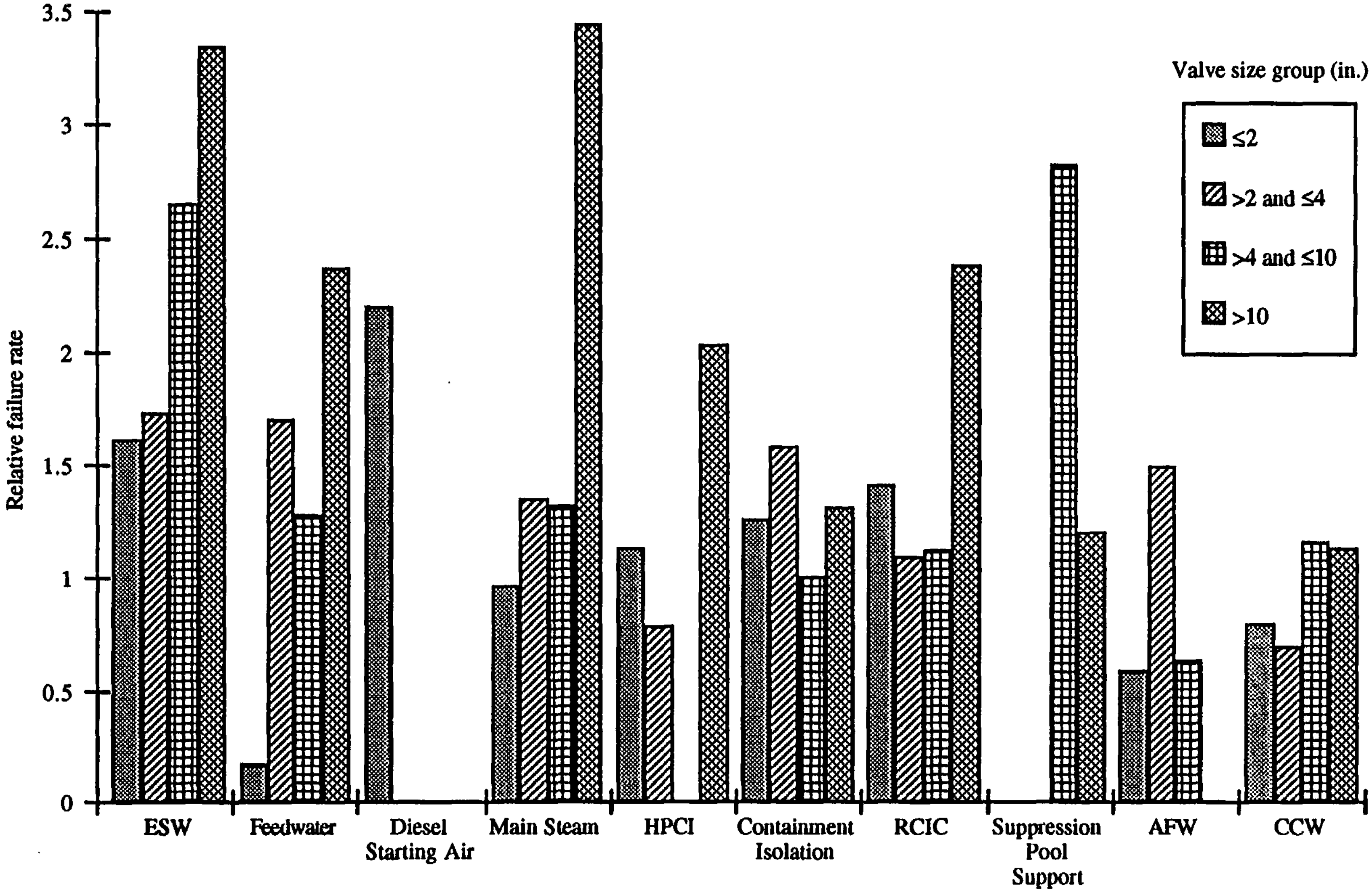


Figure A.3.3 Relative failure rate by system and valve size group

ORNL-DWG 93-7364

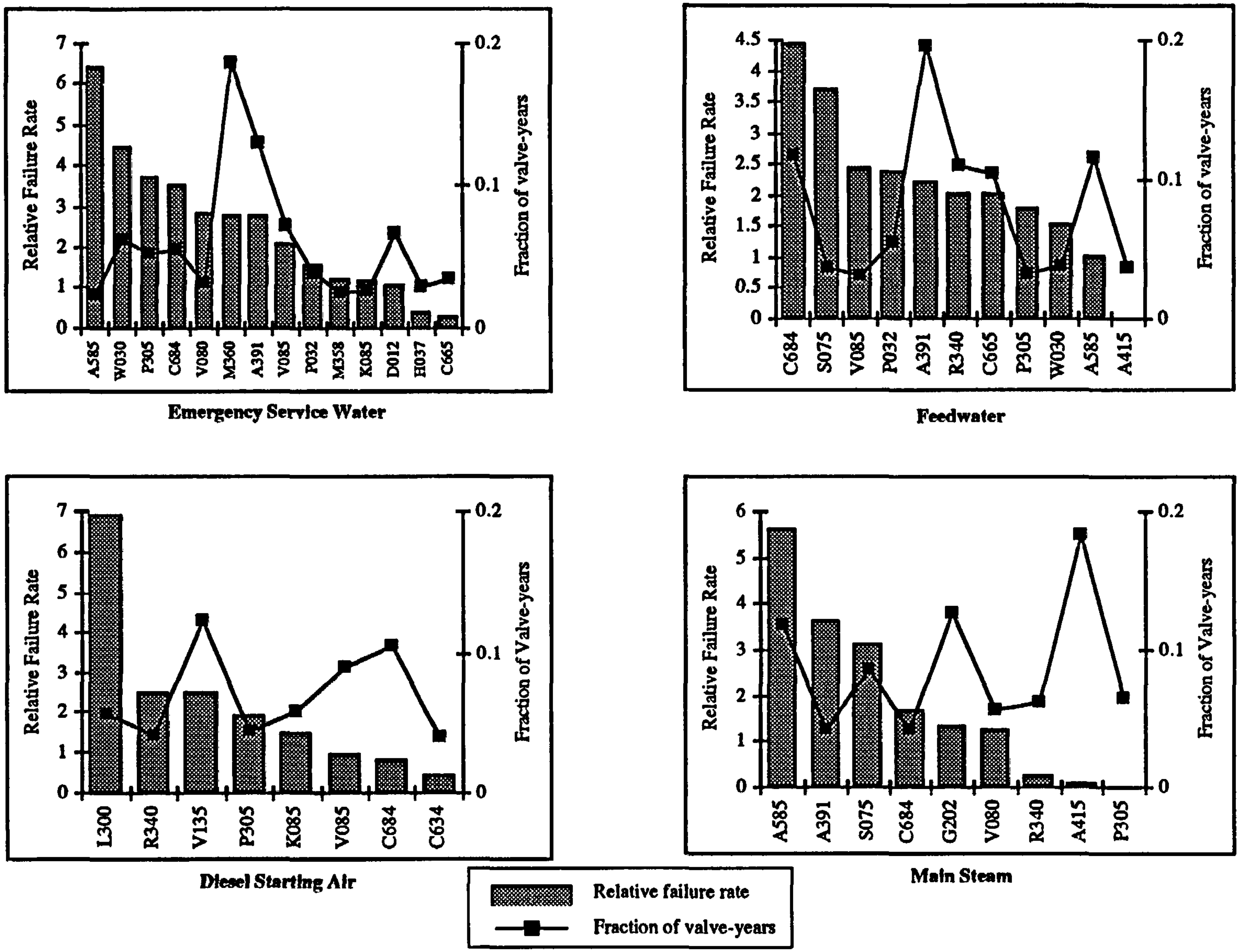


Figure A.3.4 Relative failure rates and operating experience for manufacturers with more than 200 valve-years experience in the respective system during the study period. The fraction of valve-years is for the designated system only. Results sorted by relative failure rate

ORNL-DWG 93-7365

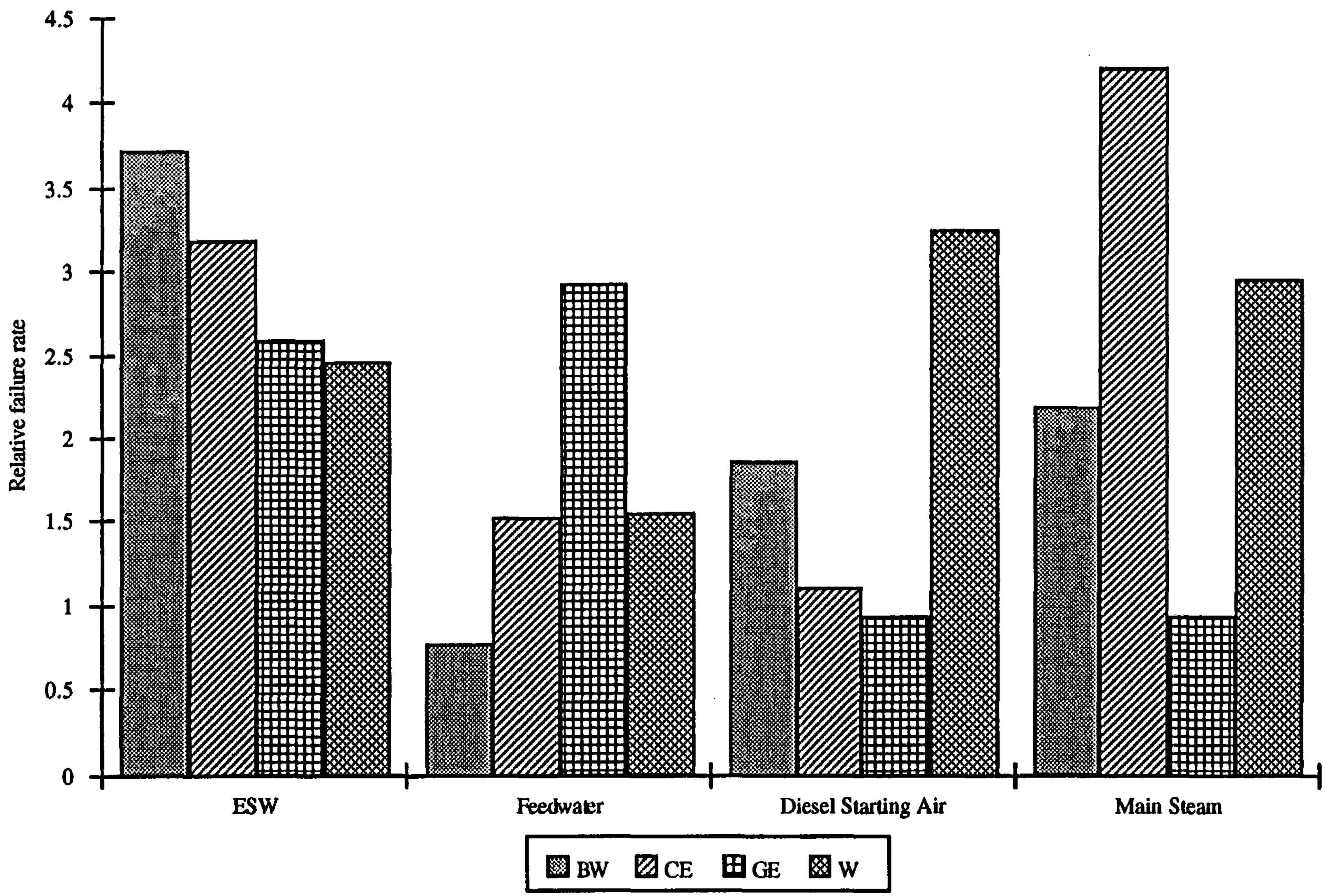


Figure A.3.5 Relative failure rate by system and NSSS for four systems with the highest overall failure rate

ORNL-DWG 93-7366

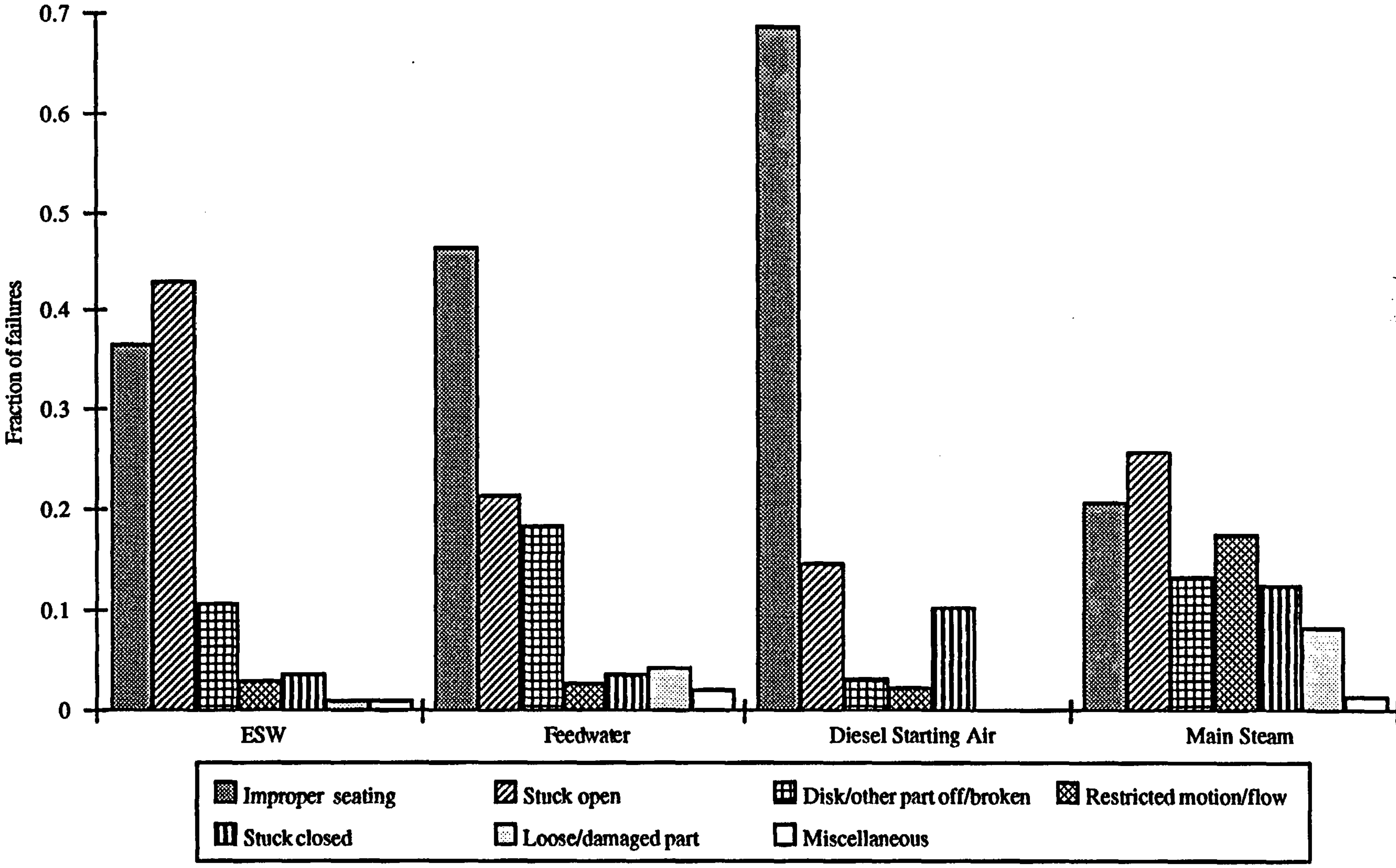


Figure A.3.6 Distribution of failures by system and failure mode for four systems with the highest overall failure rate

ORNL–DWG 93-7367

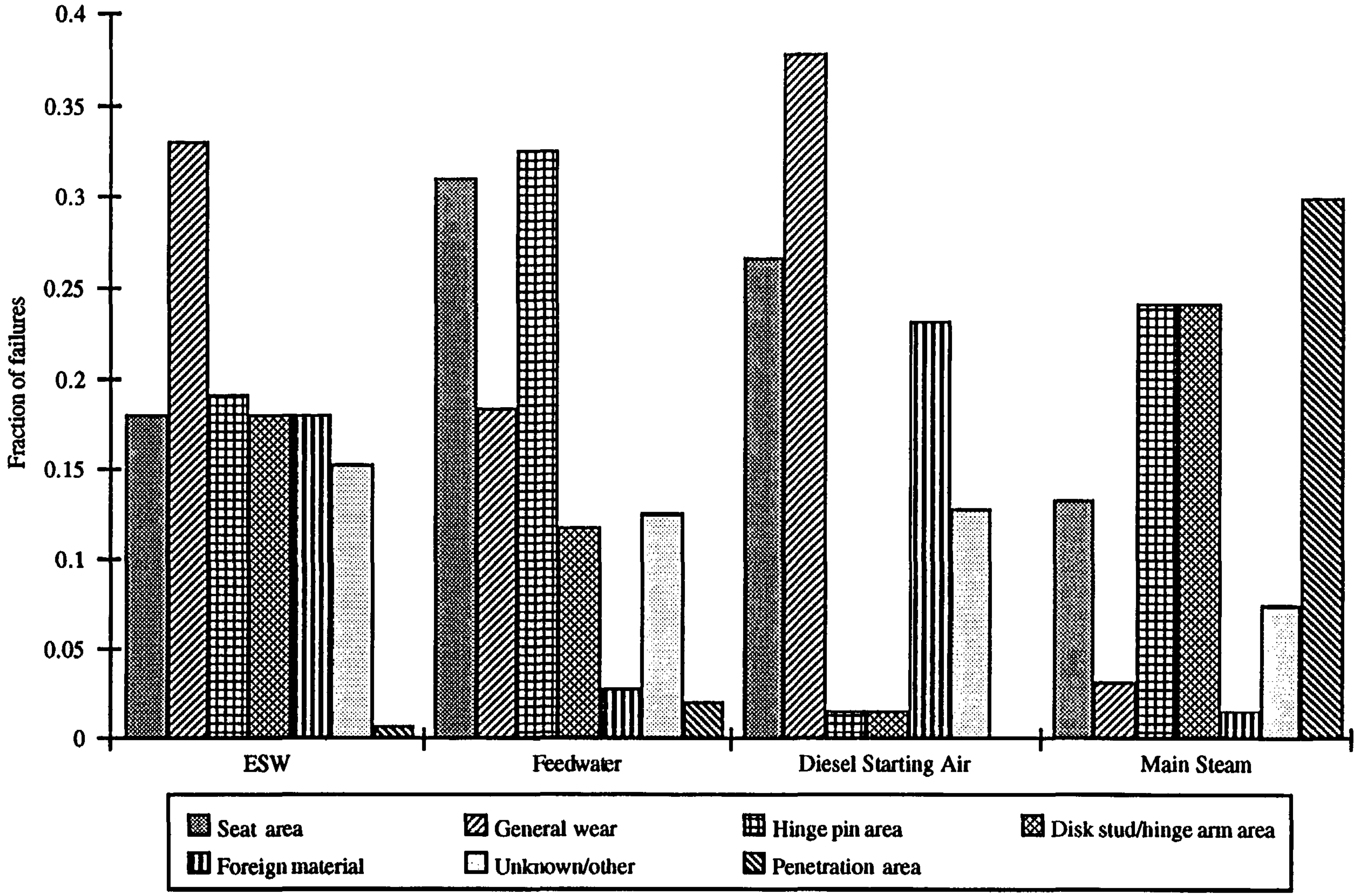


Figure A.3.7 Distribution of failures by system and failure area for four systems with the highest overall failure rate

ORNL-DWG 93-7368

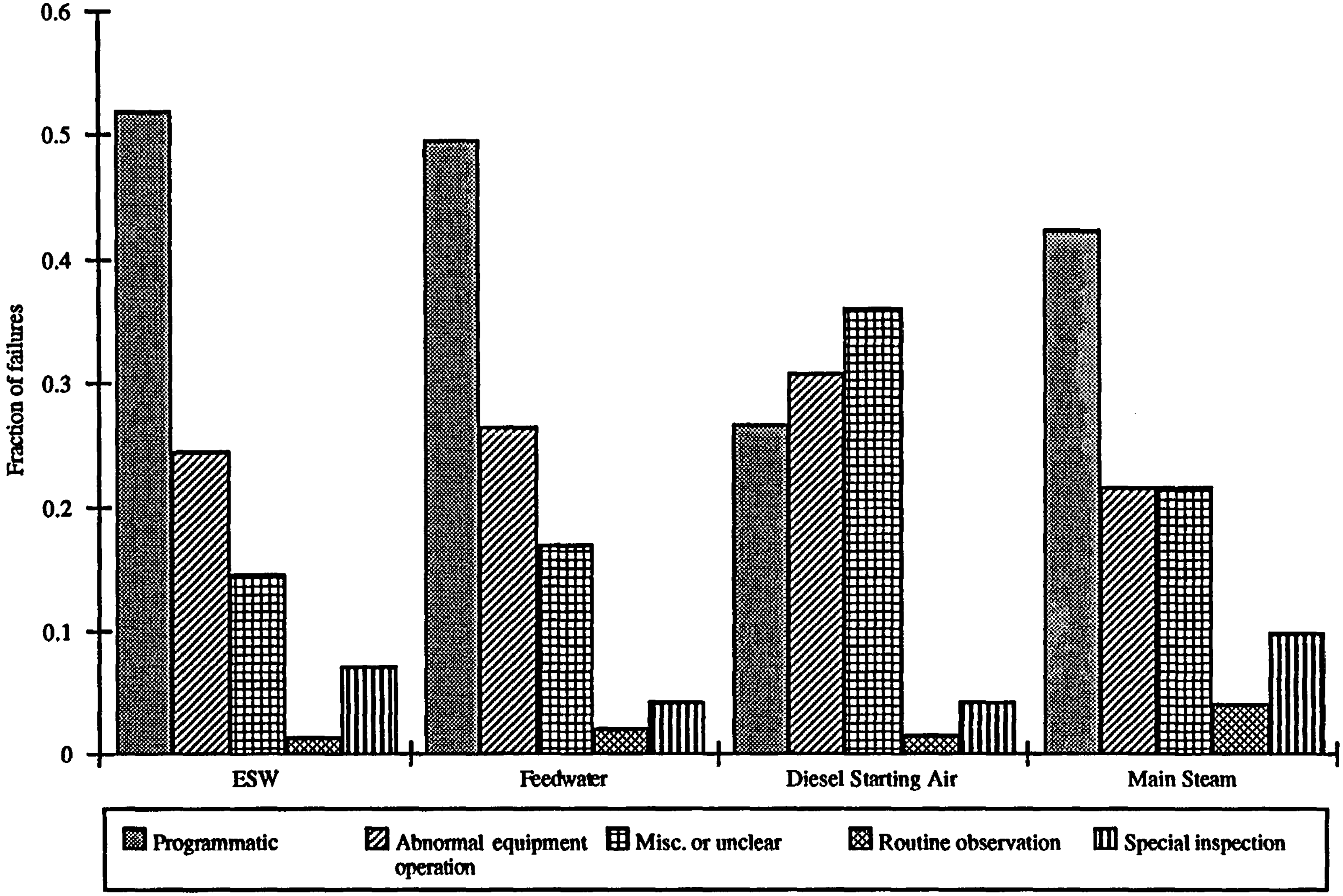


Figure A.3.8 Distribution of failures by system and general detection method for four systems with the highest overall failure rate

ORNL-DWG 93-7369

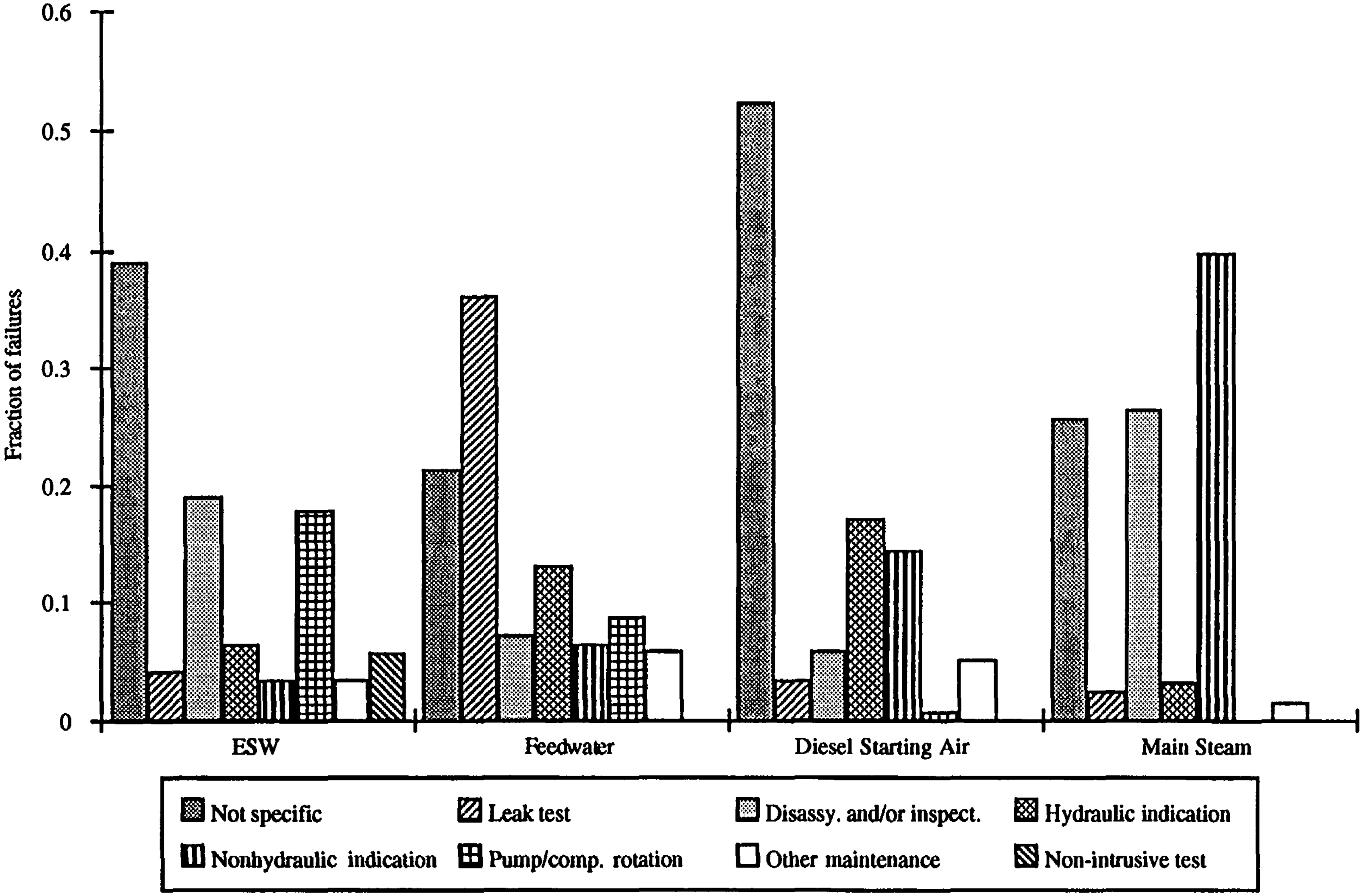


Figure A.3.9 Distribution of failures by system and specific detection method for four systems with the highest overall failure rate

ORNL-DWG 93-7370

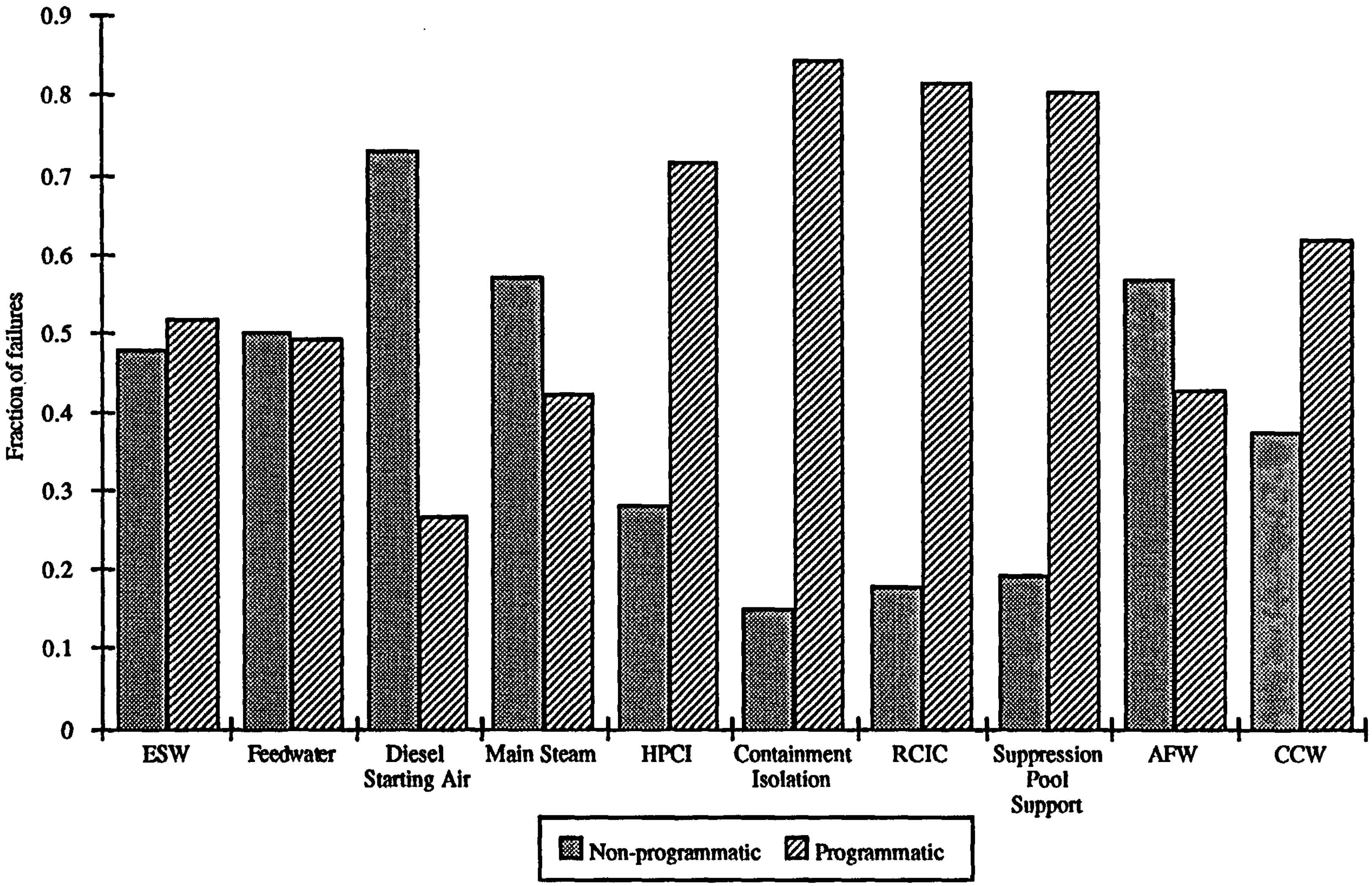


Figure A.3.10 Distribution of failures by system and discovery process for ten systems with the highest overall failure rate

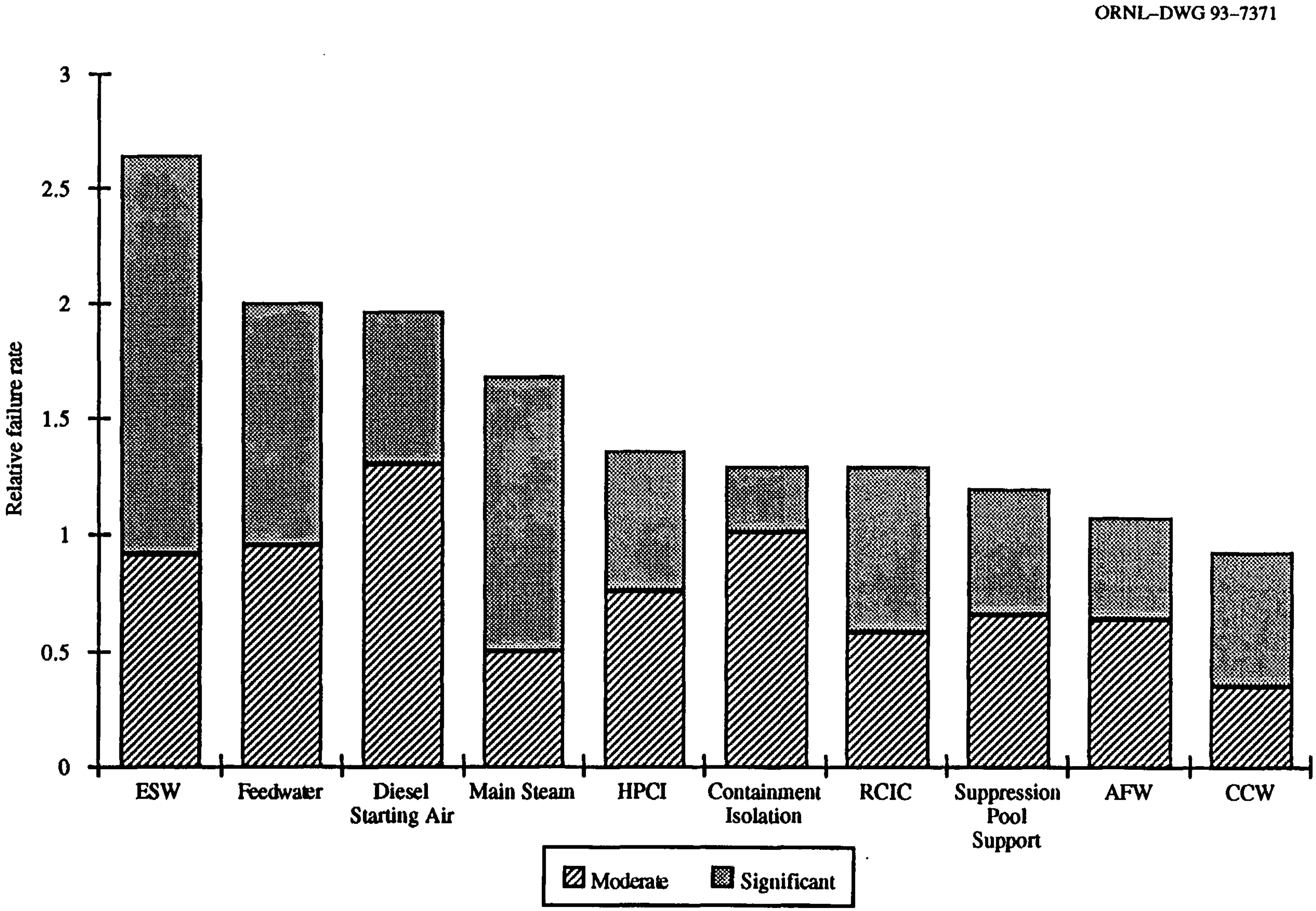


Figure A.3.11 Allocation of relative failure rate by system and extent of degradation for ten systems with the highest overall failure rate

ORNL-DWG 93-7372

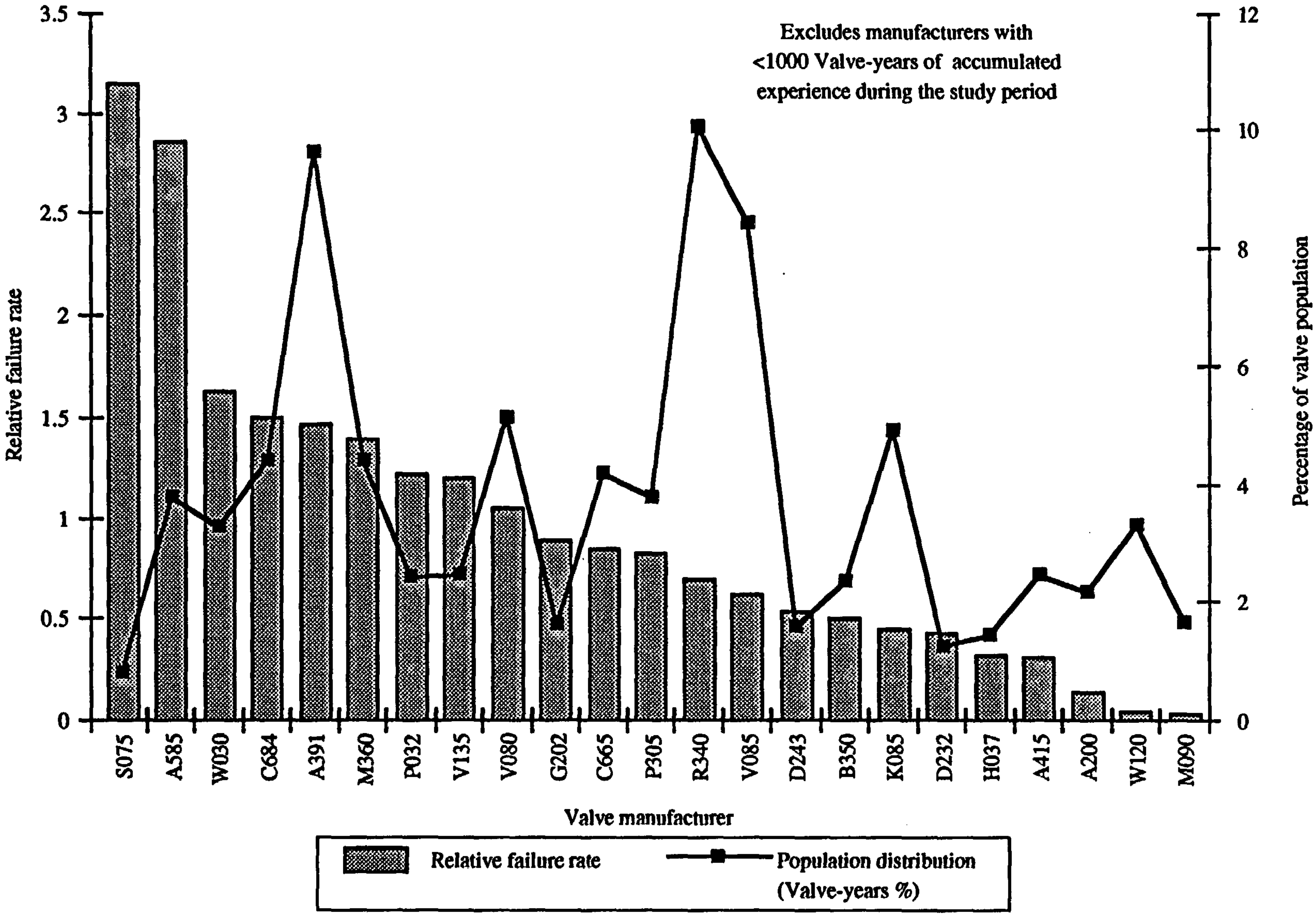


Figure A.4.1 Relative failure rate and service population by manufacturer

ORNL-DWG 93-7373

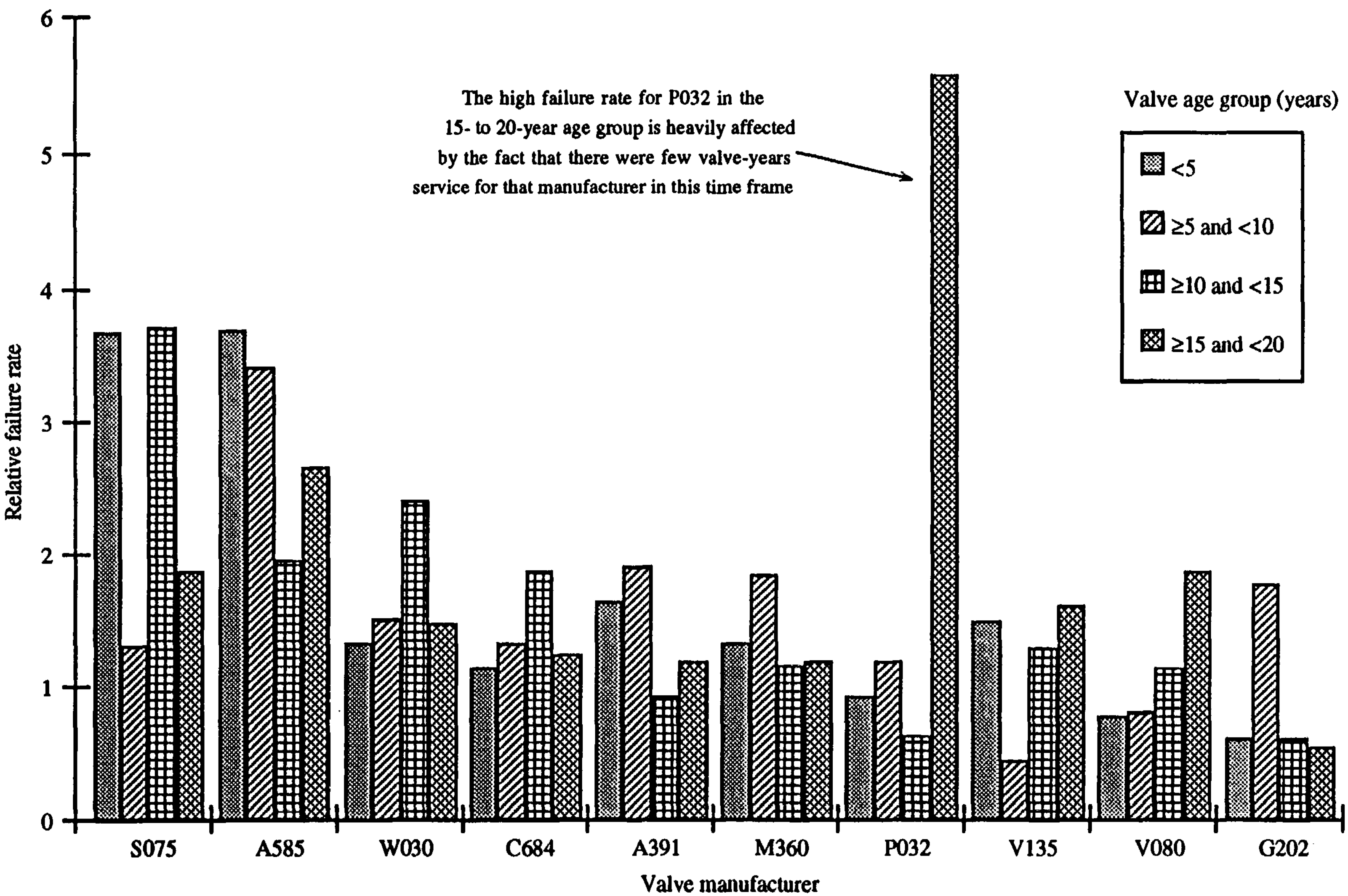


Figure A.4.2 Relative failure rate by manufacturer and valve age group for the ten manufacturers with the highest overall relative failure rates

ORNL-DWG 93-7374

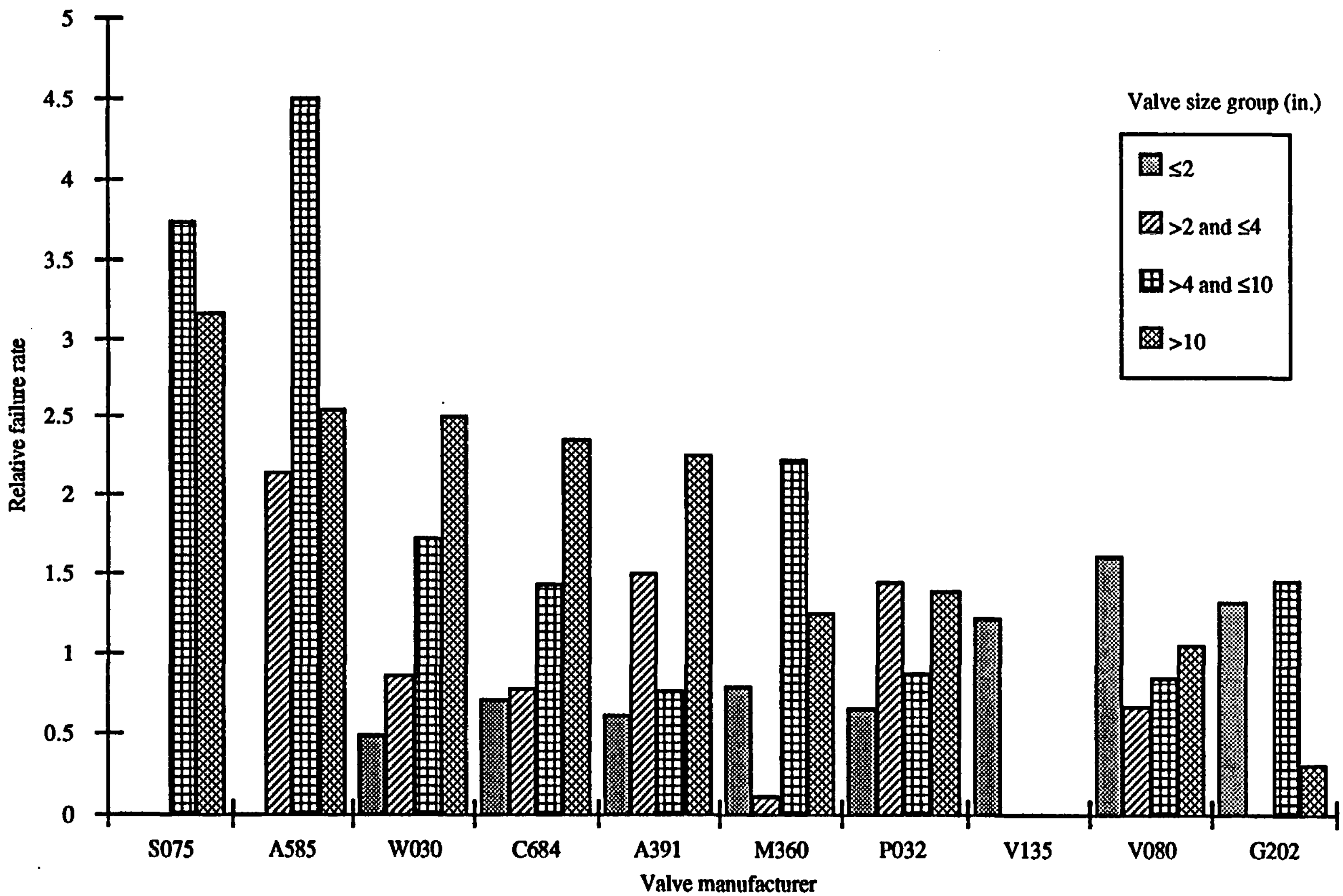


Figure A.4.3 Relative failure rate by valve manufacturer and size for the ten manufacturers with the highest overall relative failure rates

ORNL-DWG 93-7375

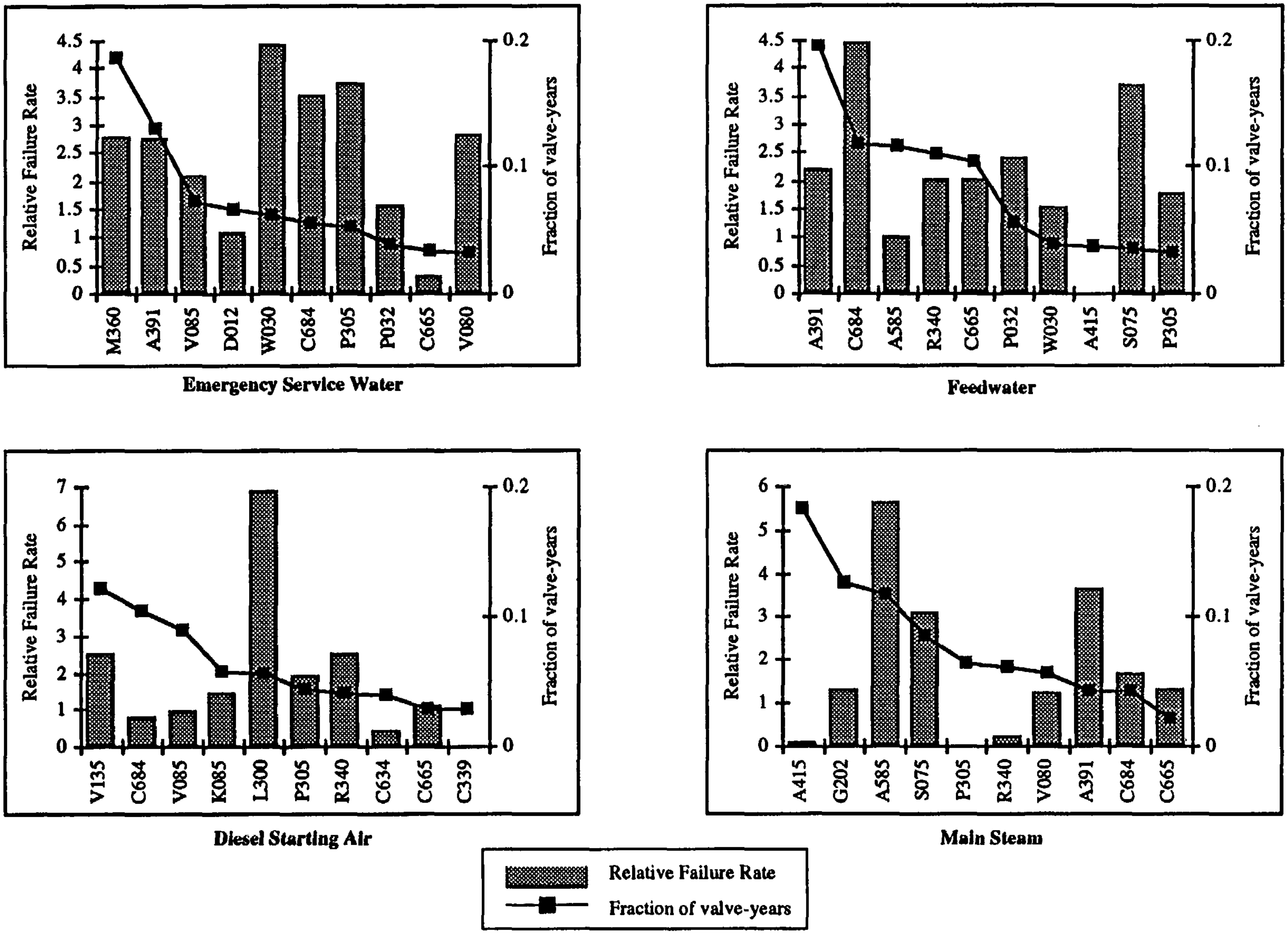


Figure A.4.4 Relative failure rates and operating experience for the ten manufacturers with the greatest valve population in the respective systems during the study period. Results sorted by manufacturer population

ORNL-DWG 93-7376

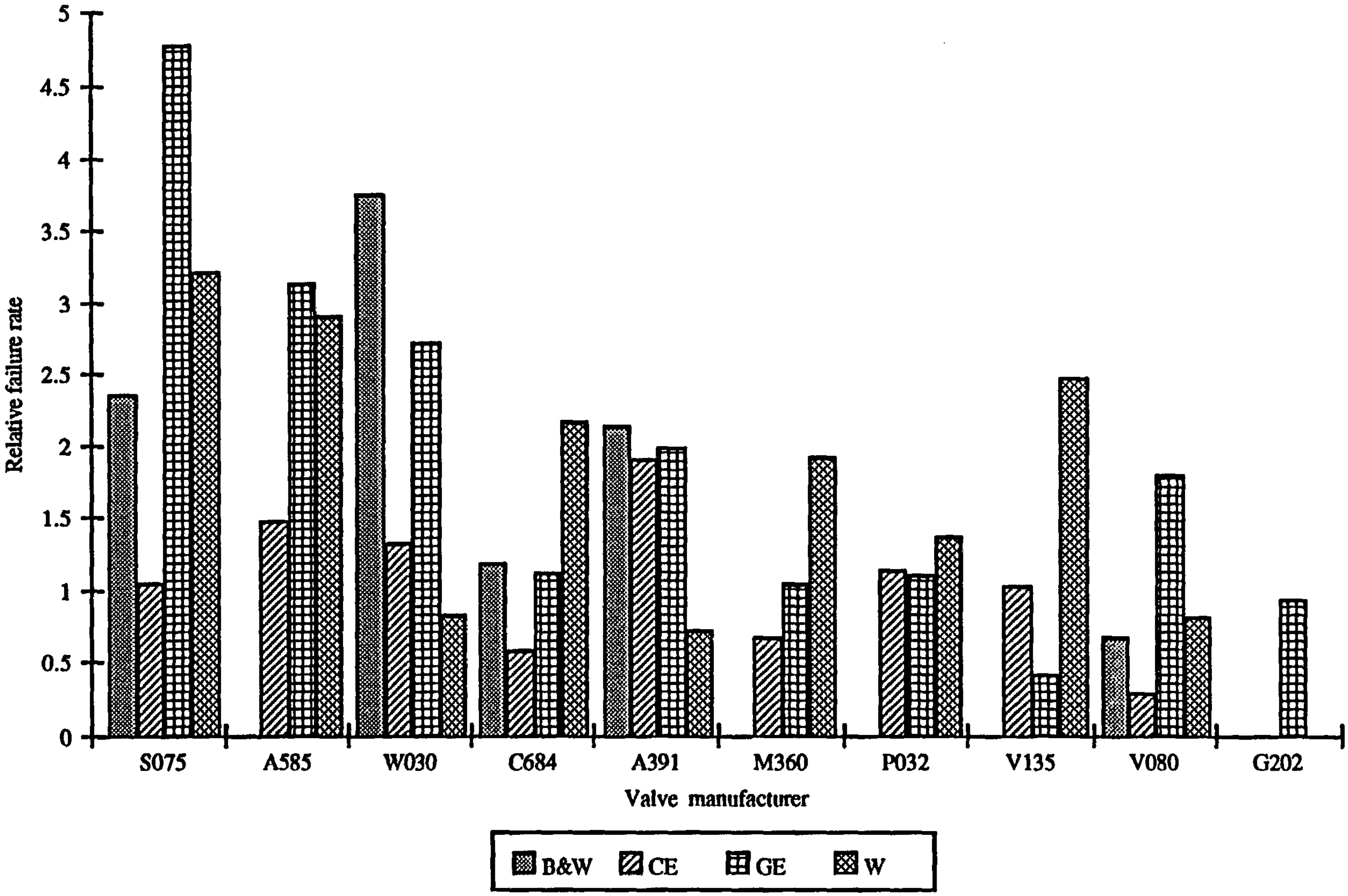


Figure A.4.5 Relative failure rate by NSSS for ten manufacturers with the highest overall failure rate. Sorted by overall relative failure rate

ORNL-DWG 93-7377

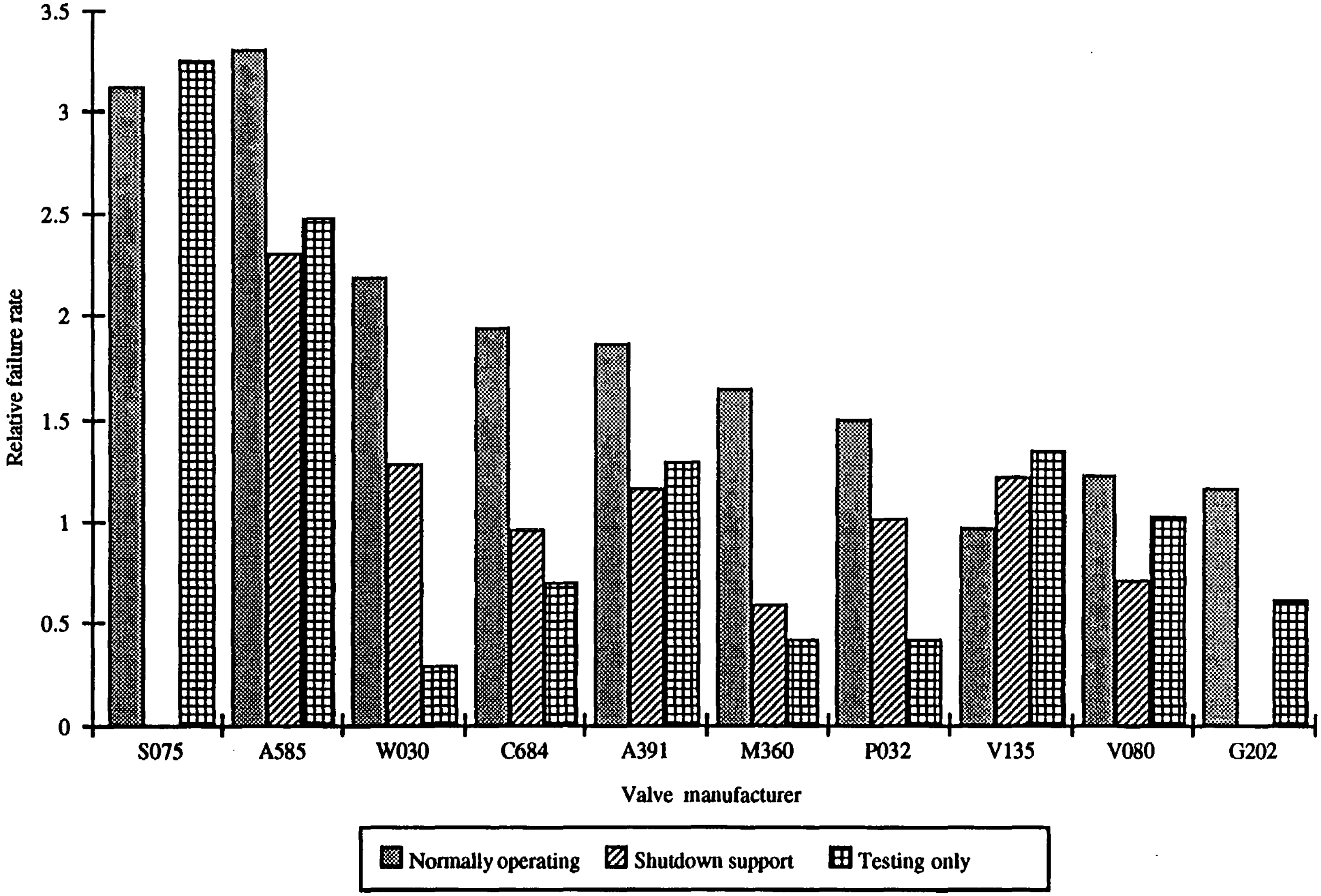


Figure A.4.6 Relative failure rates for the ten manufacturers with the overall highest failure rate by normal system status

ORNL–DWG 93–7378

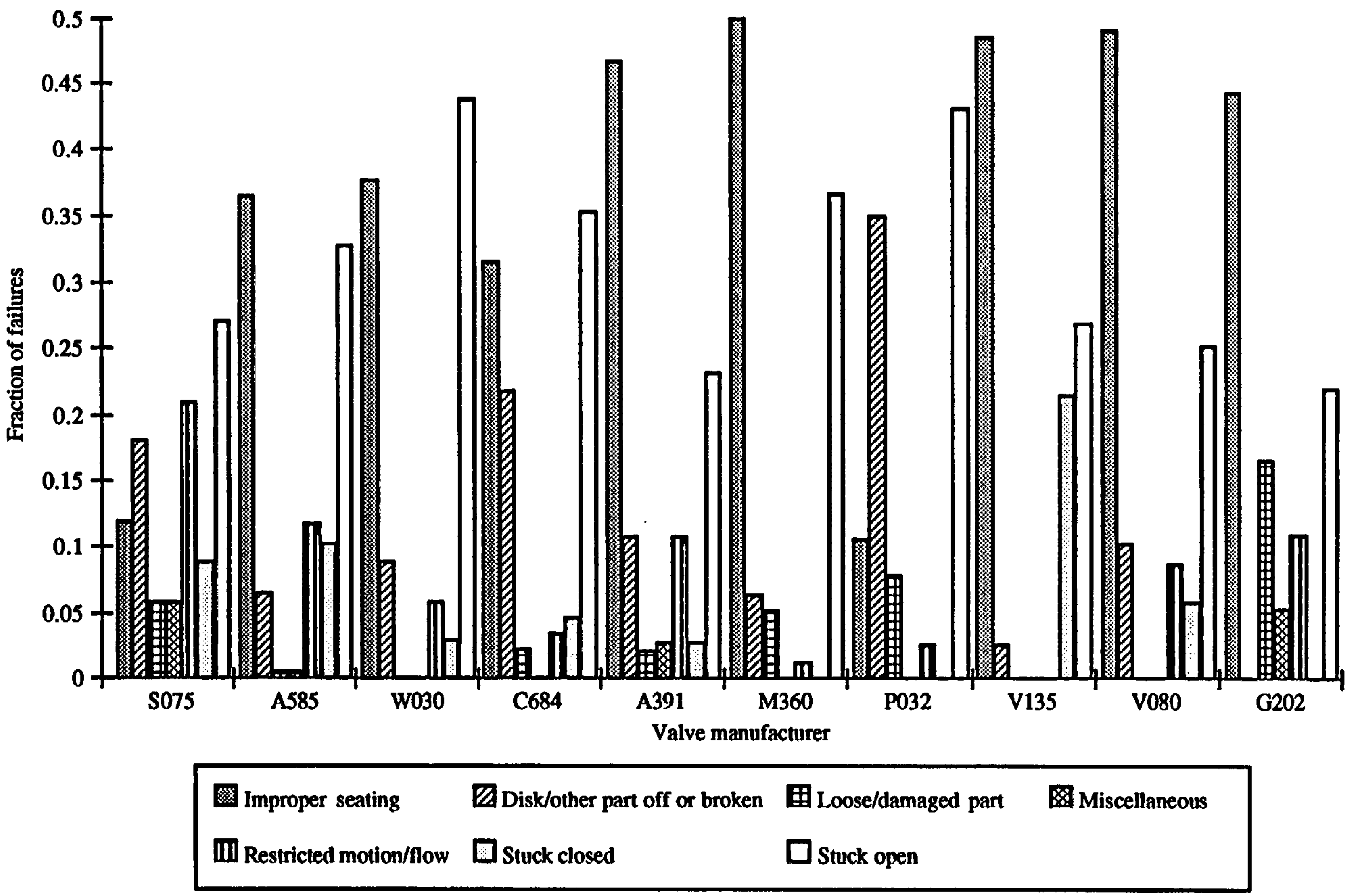


Figure A.4.7 Distribution of failures by manufacturer and failure mode for ten manufacturers with the overall highest failure rate. The sum of the values shown for each manufacturer equals one

ORNL–DWG 93–7379

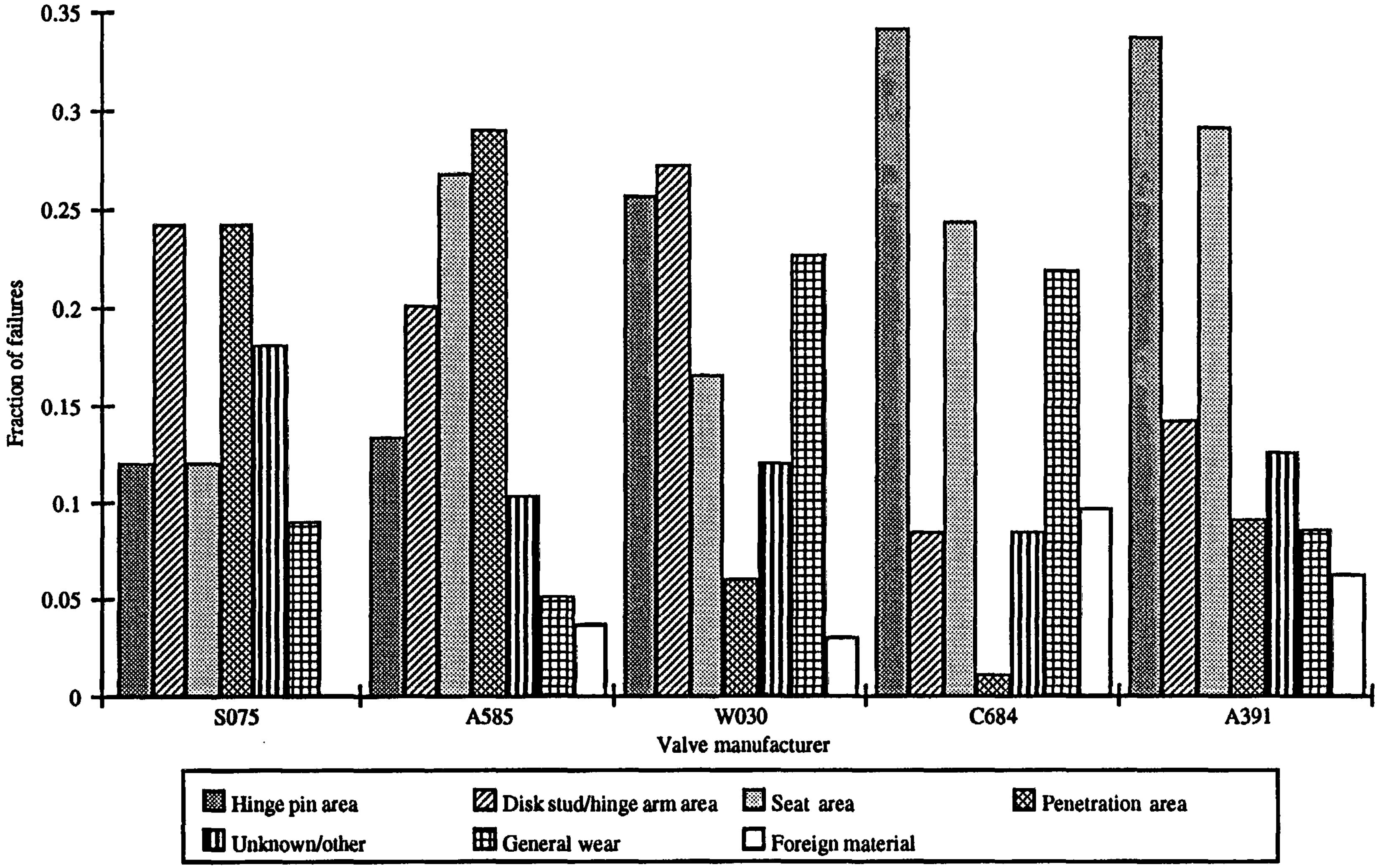


Figure A.4.8 Fraction of failures by manufacturer in which the designated valve area was affected. Manufacturers shown are the five manufacturers with the highest overall relative failure rates. Note that the sum of the fractions for each manufacturer may exceed one due to multiple areas being affected in some cases

ORNL-DWG 93-7380

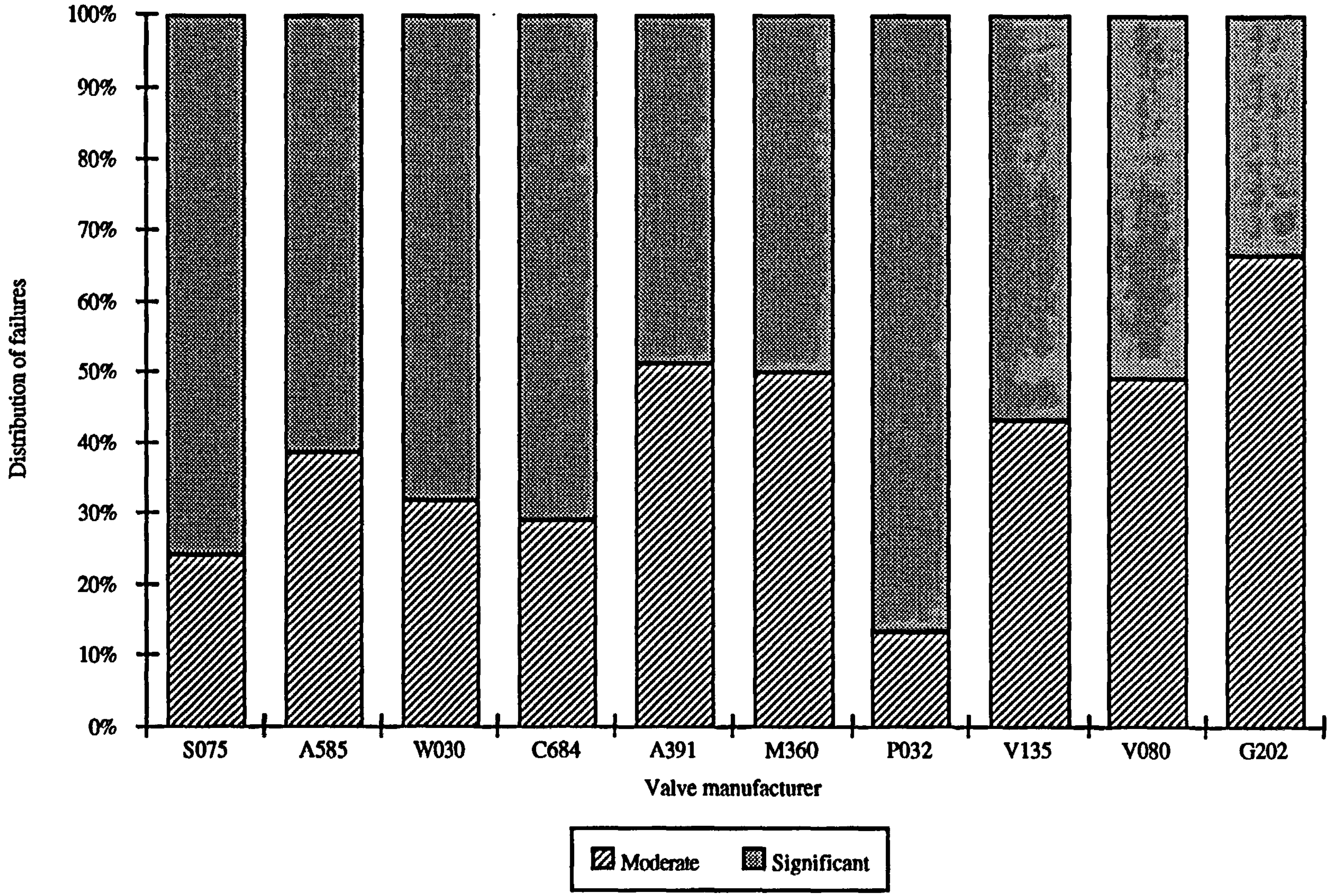


Figure A.4.9 Distribution of failures by extent of degradation for ten manufacturers with highest overall failure rate

ORNL-DWG 93-7381

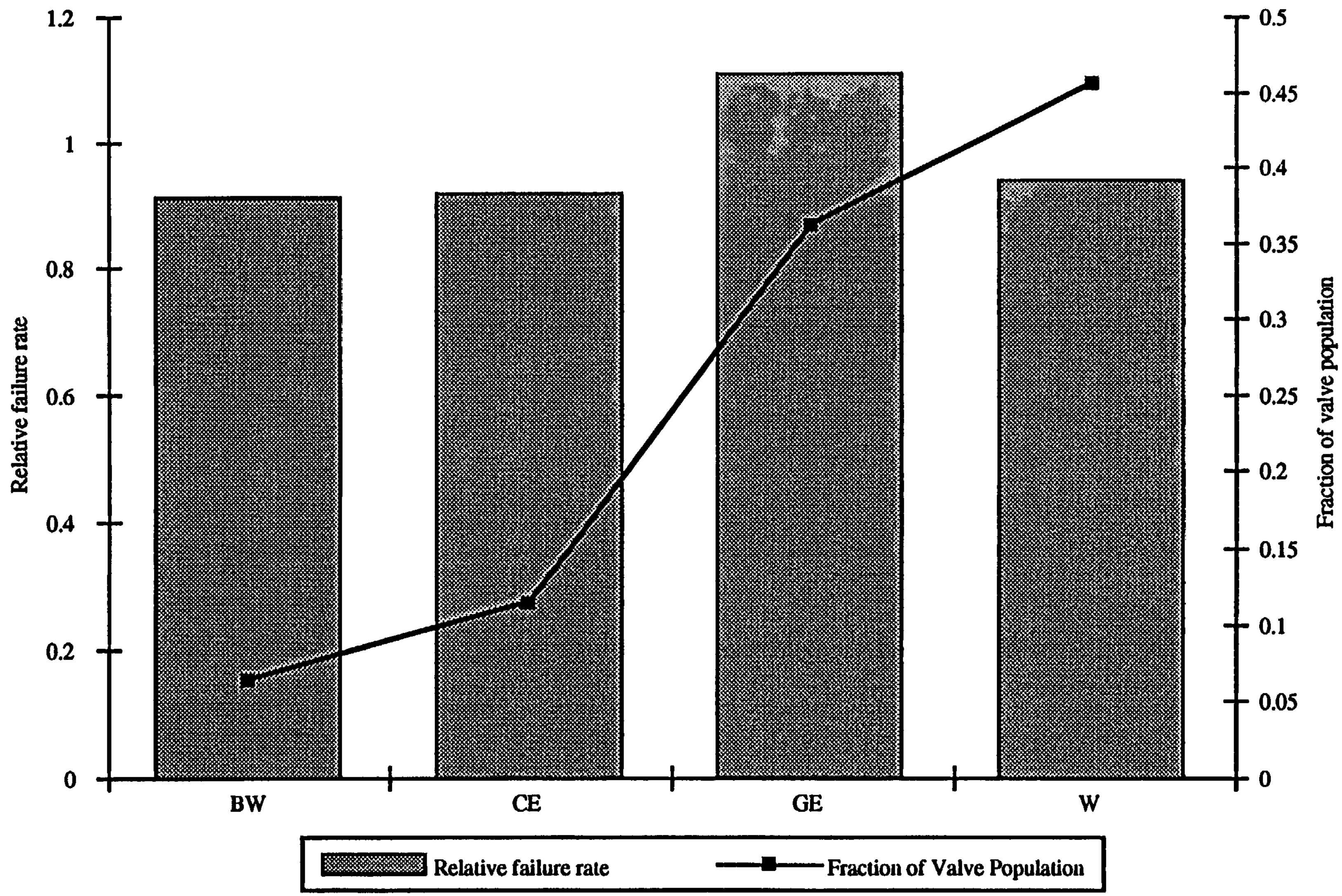


Figure A.5.1 Relative failure rate and operating experience by NSSS

ORNL–DWG 93–7382

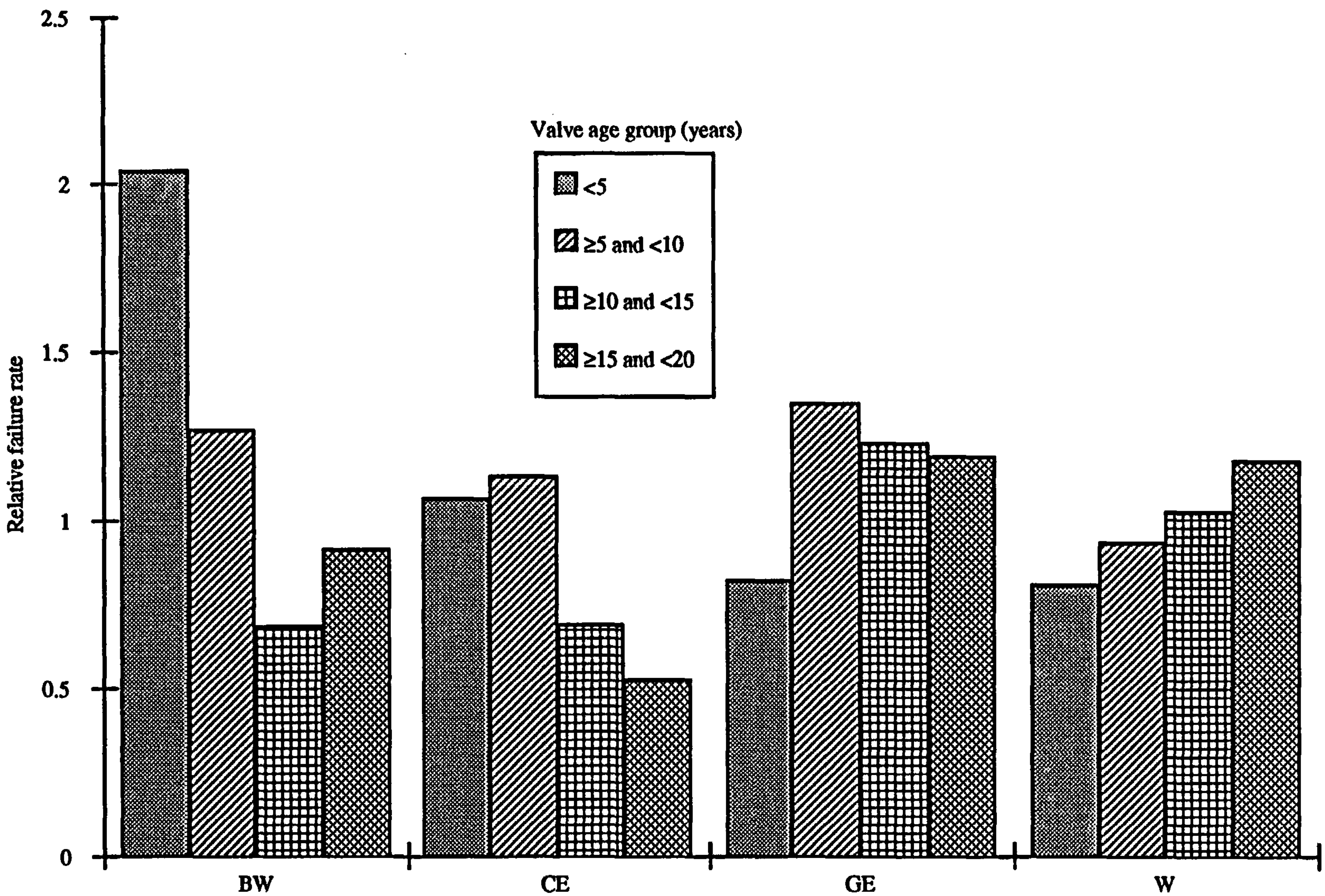


Figure A.5.2 Relative failure rate by NSSS and valve age group

ORNL-DWG 93-7383

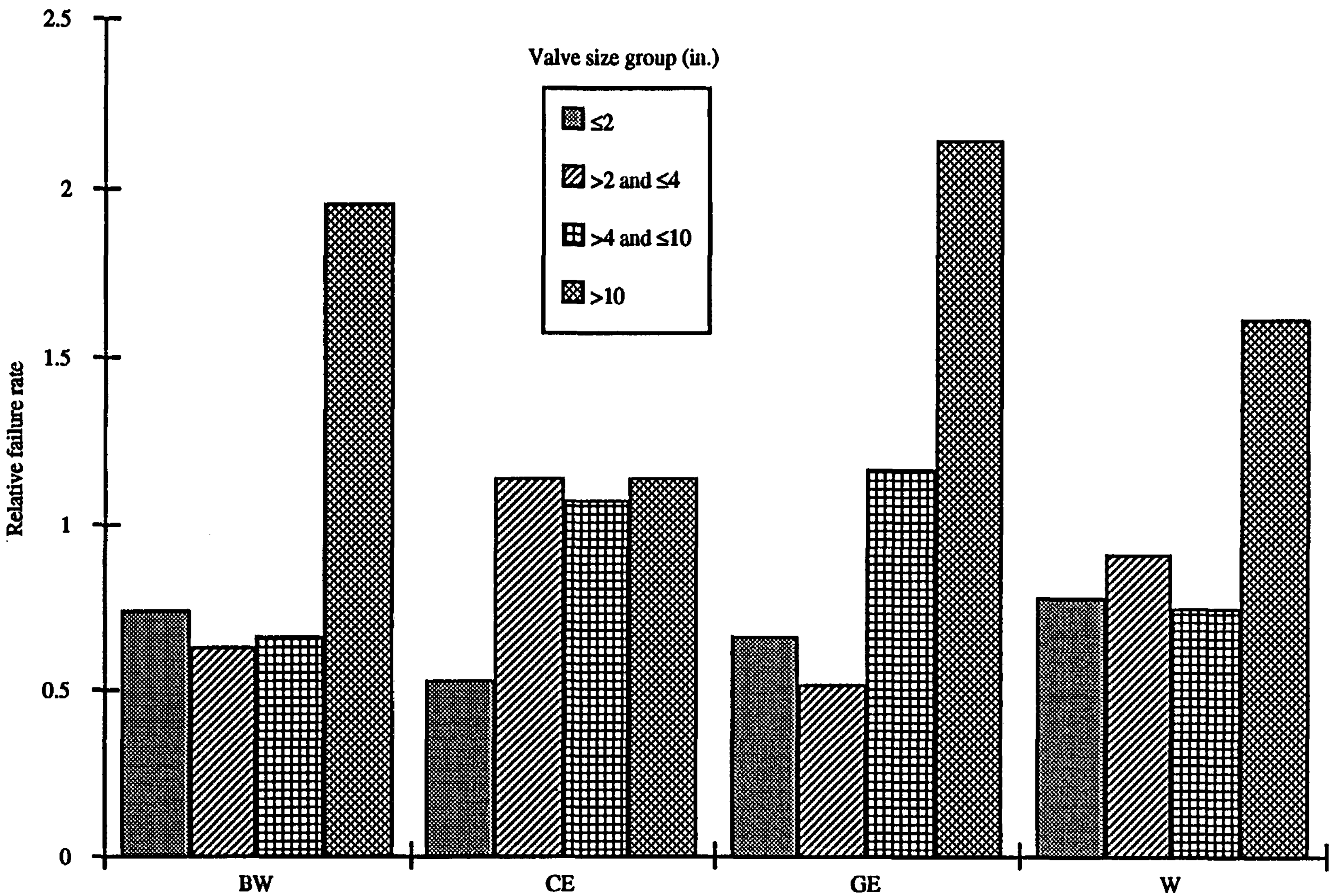


Figure A.5.3 Relative failure rate by NSSS and valve size group

ORNL–DWG 93–7384

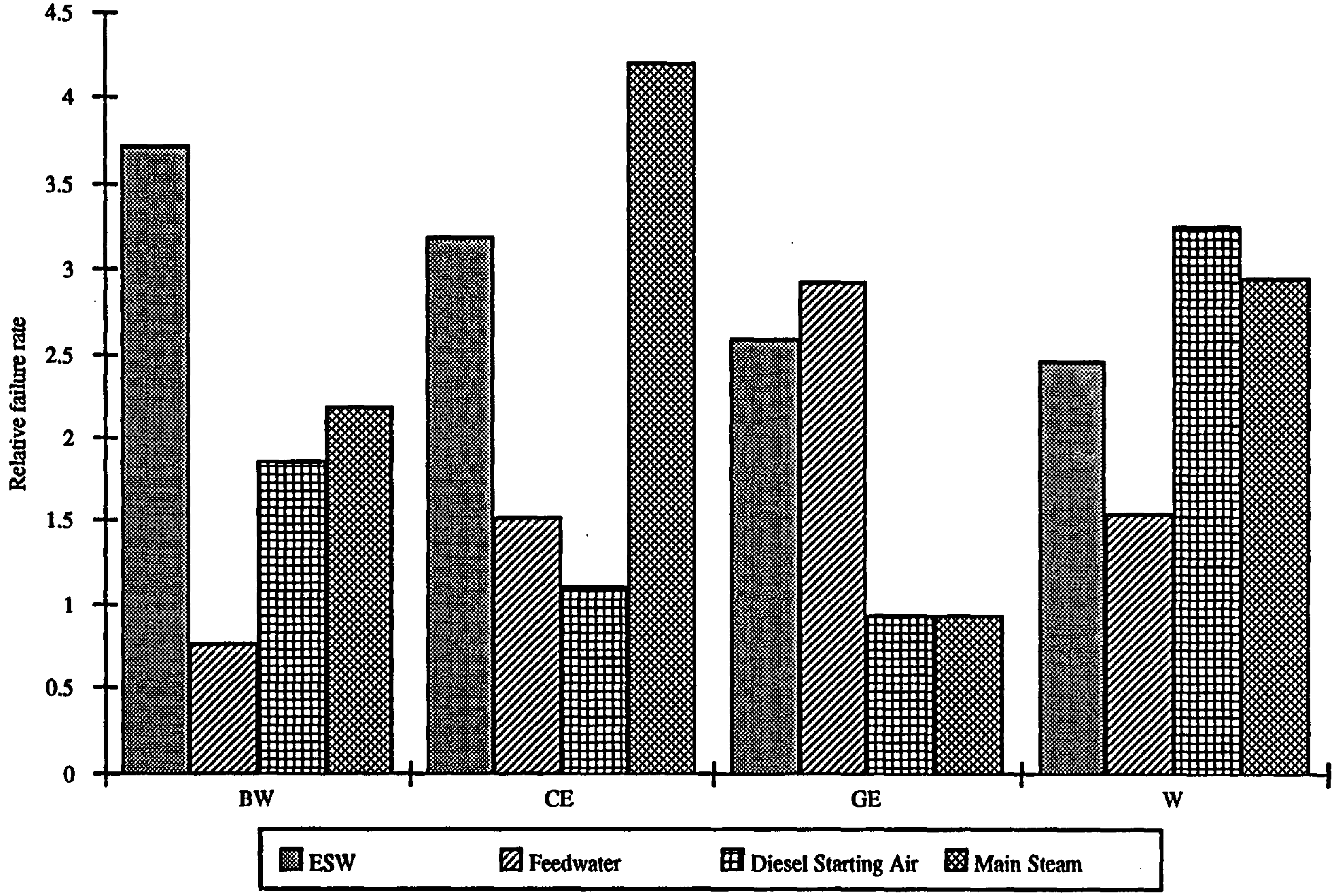


Figure A.5.4 Relative failure rate by NSSS and system for four systems with the highest overall failure rate

ORNL-DWG 93-7385

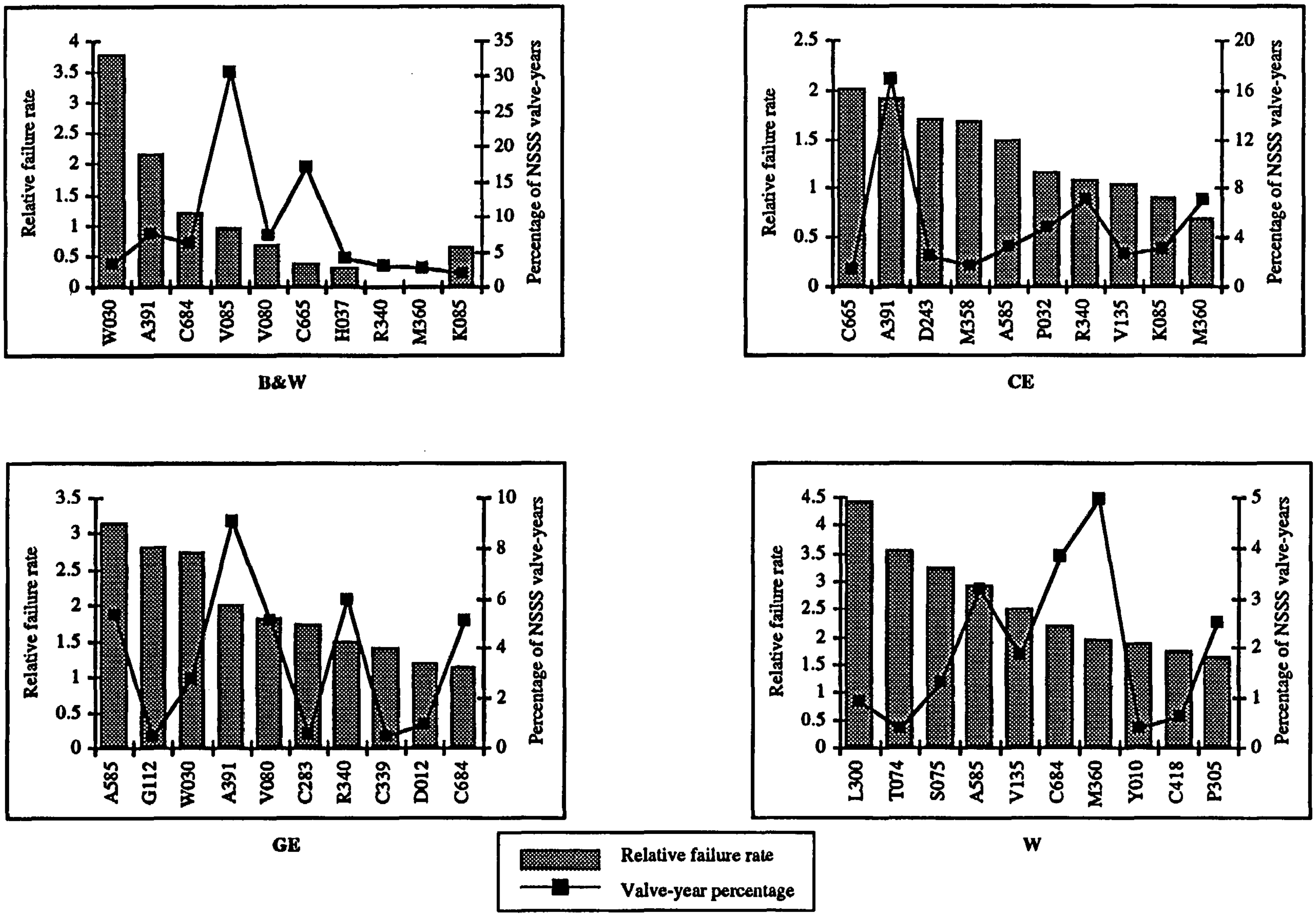


Figure A.5.5 Relative failure rate and population percentage for ten manufacturers with highest overall failure rate within the NSSS. Sorted by relative failure rate

ORNL-DWG 93-7386

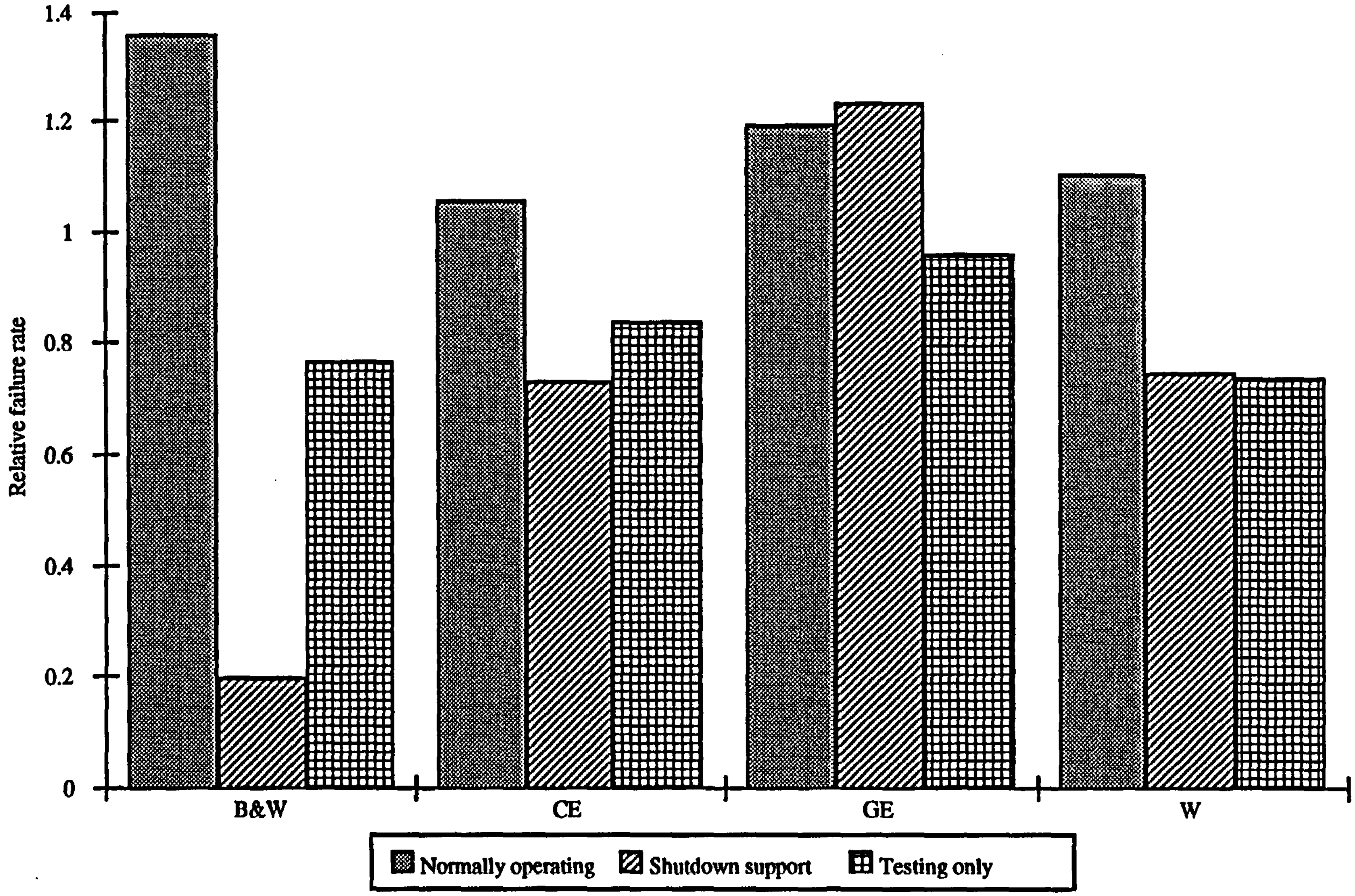


Figure A.5.6 Relative failure rate by NSSS and system status.

ORNL-DWG 93-7387

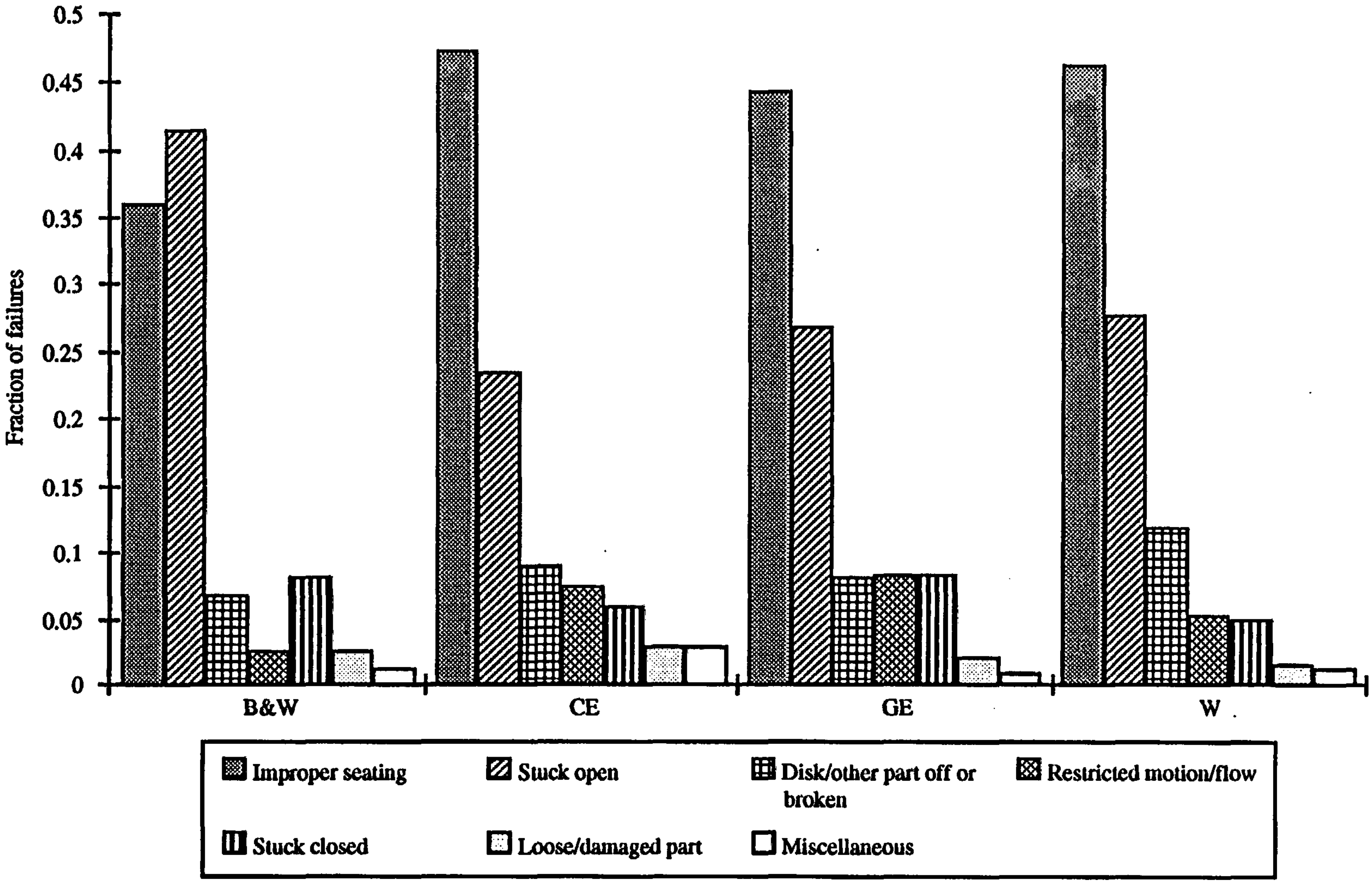


Figure A.5.7 Distribution of failures by failure mode for NSSS

ORNL–DWG 93–7388

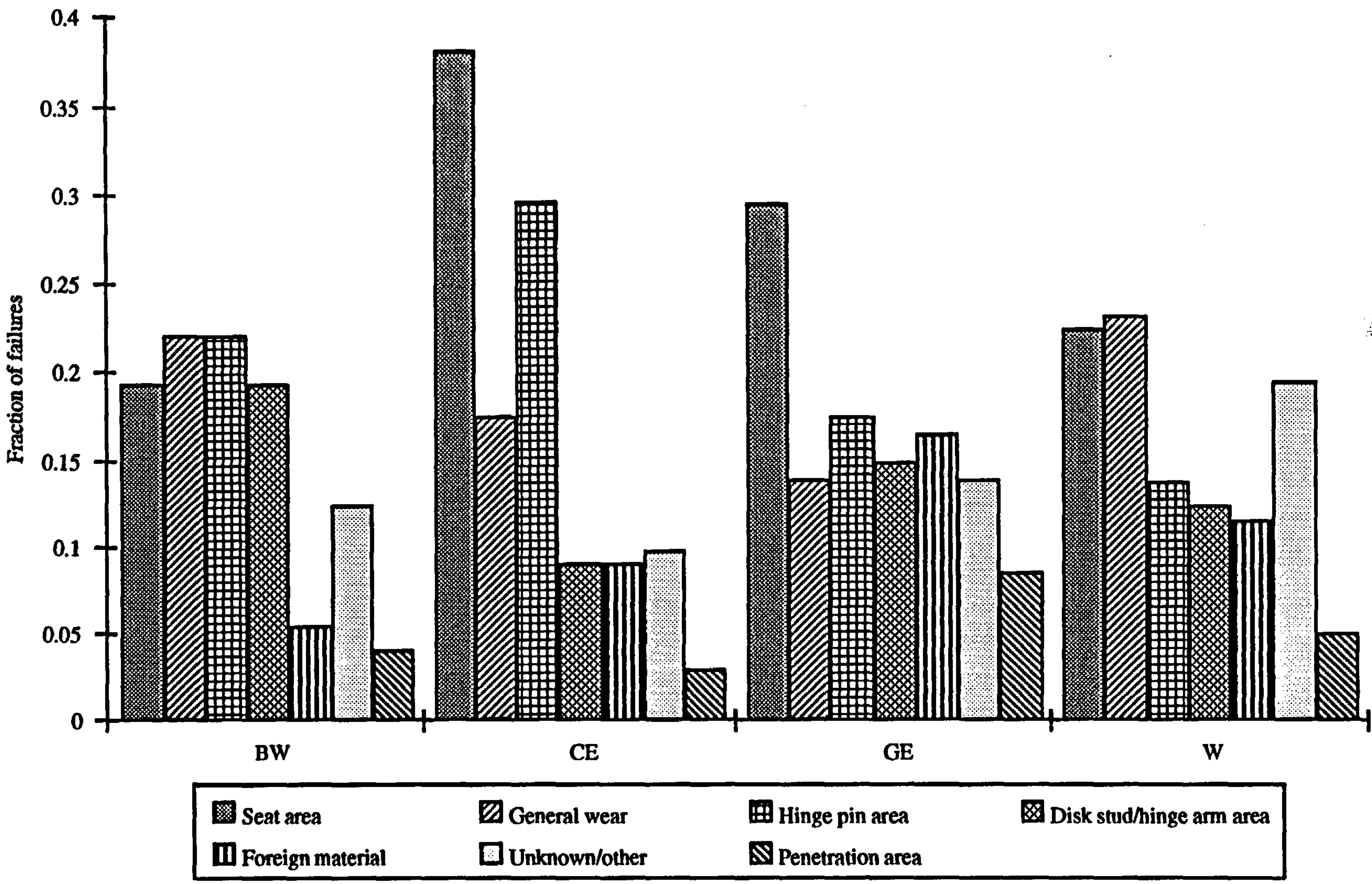


Figure A.5.8 Distribution of failures by failure area for NSSS. The sum of the values for each NSSS exceeds one because some failures affected more than one area

ORNL–DWG 93–7389

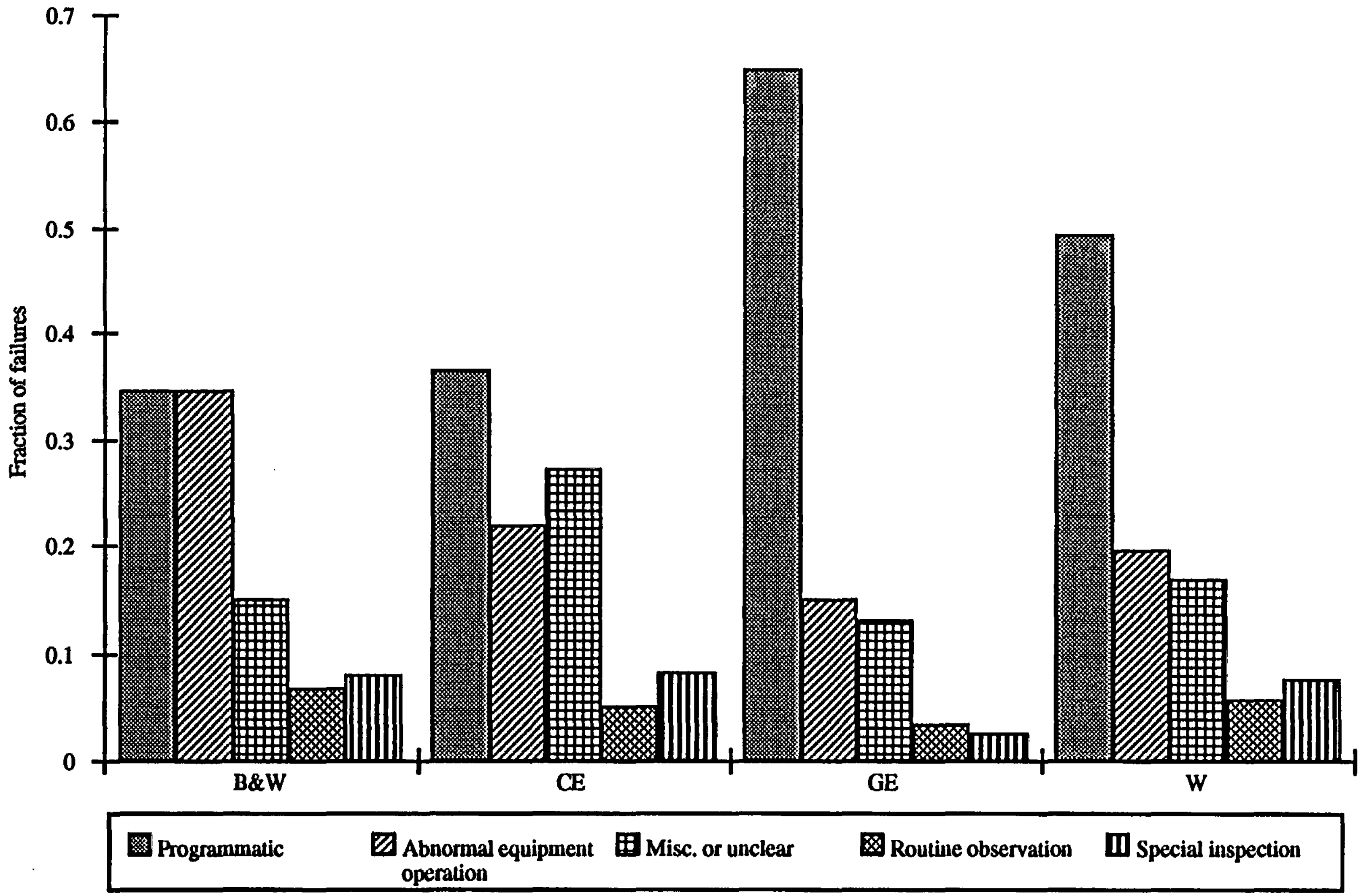


Figure A.5.9 Distribution of failures by NSSS and general detection method

ORNL-DWG 93-7390

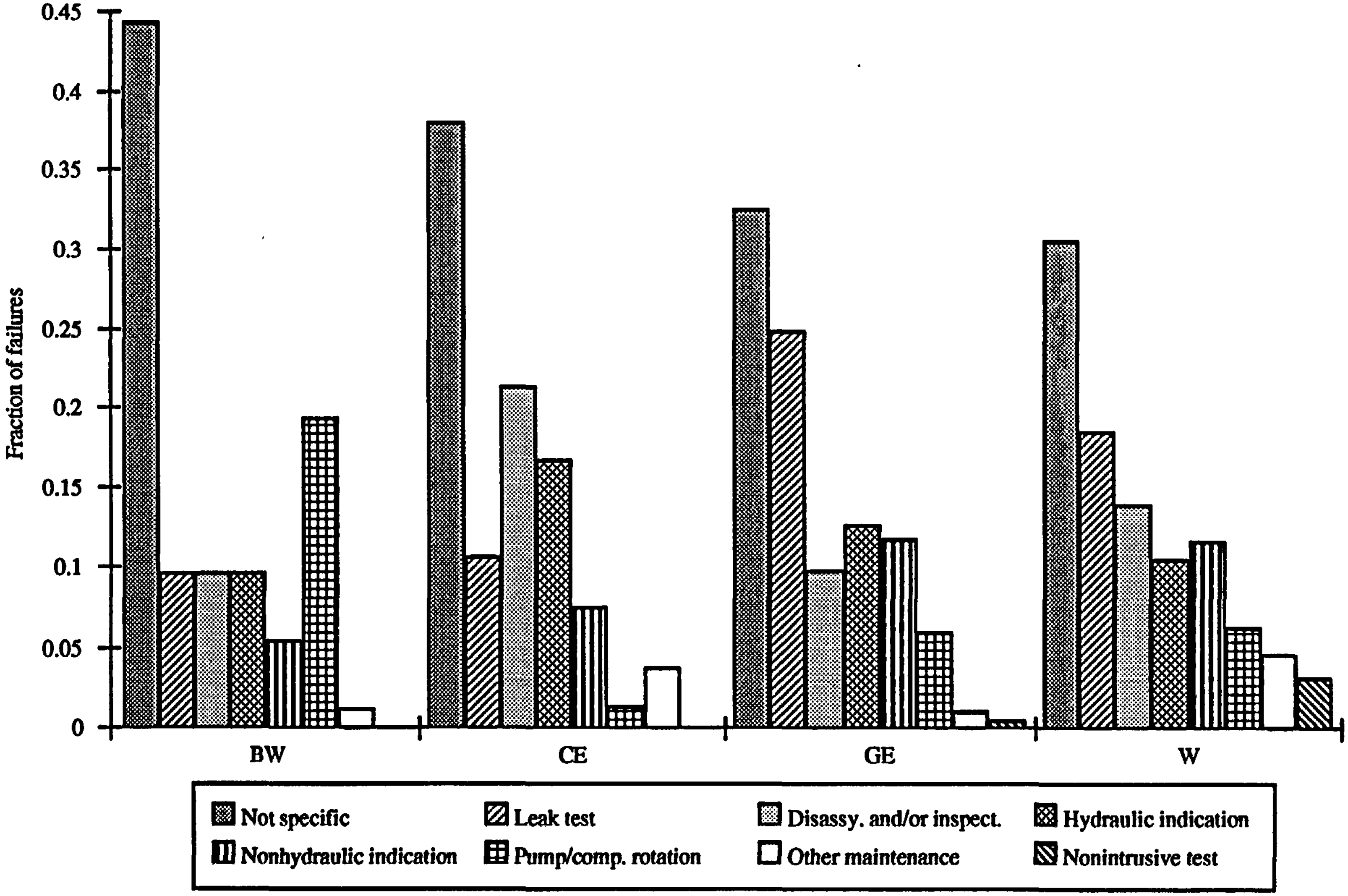


Figure A.5.10 Distribution of failures by NSSS and specific detection method

ORNL-DWG 93-7391

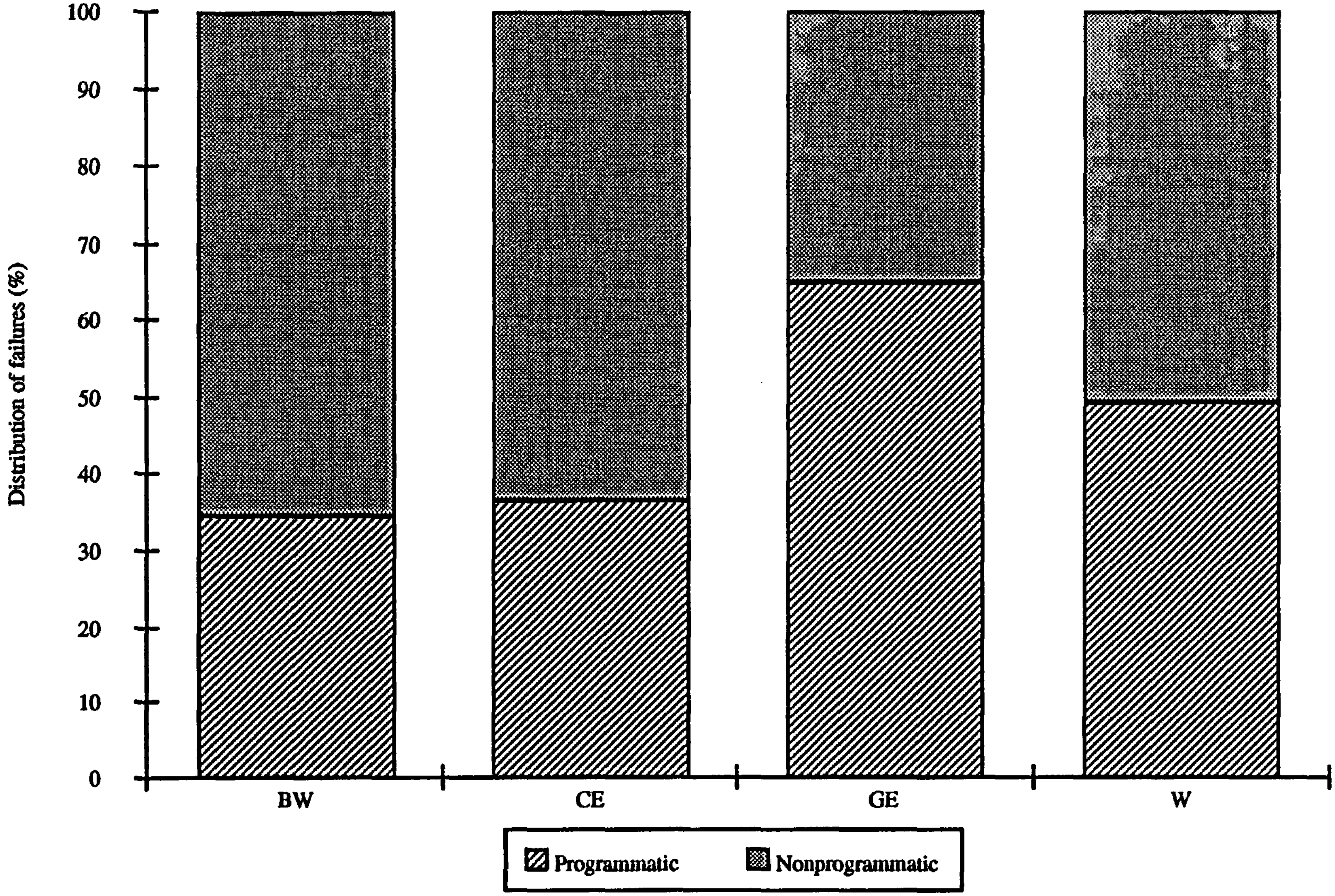


Figure A.5.11 Distribution of failures by NSSS and discovery process

ORNL-DWG 93-7392

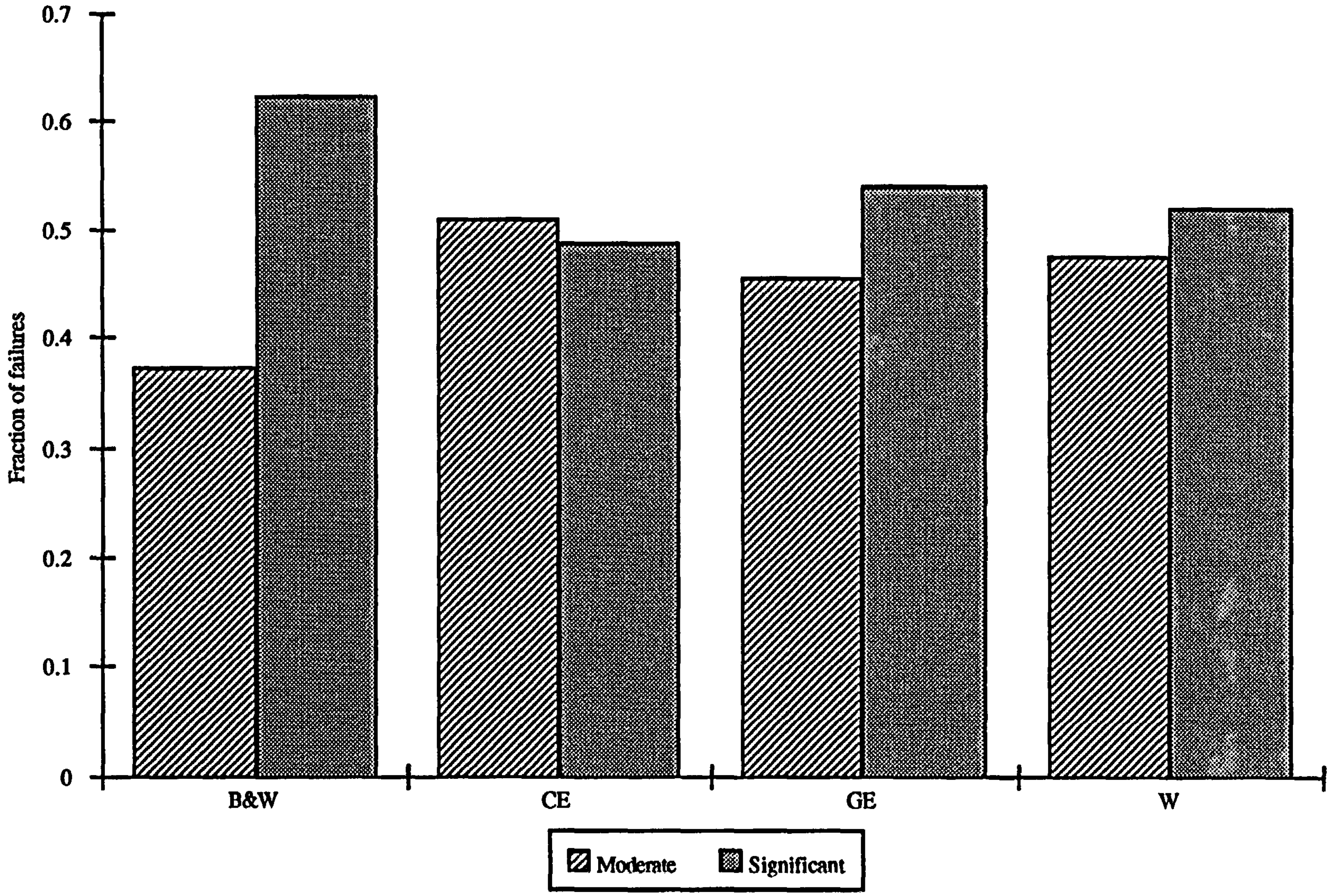


Figure A.5.12 Distribution of failures by NSSS and extent of degradation

ORNL–DWG 93–7393

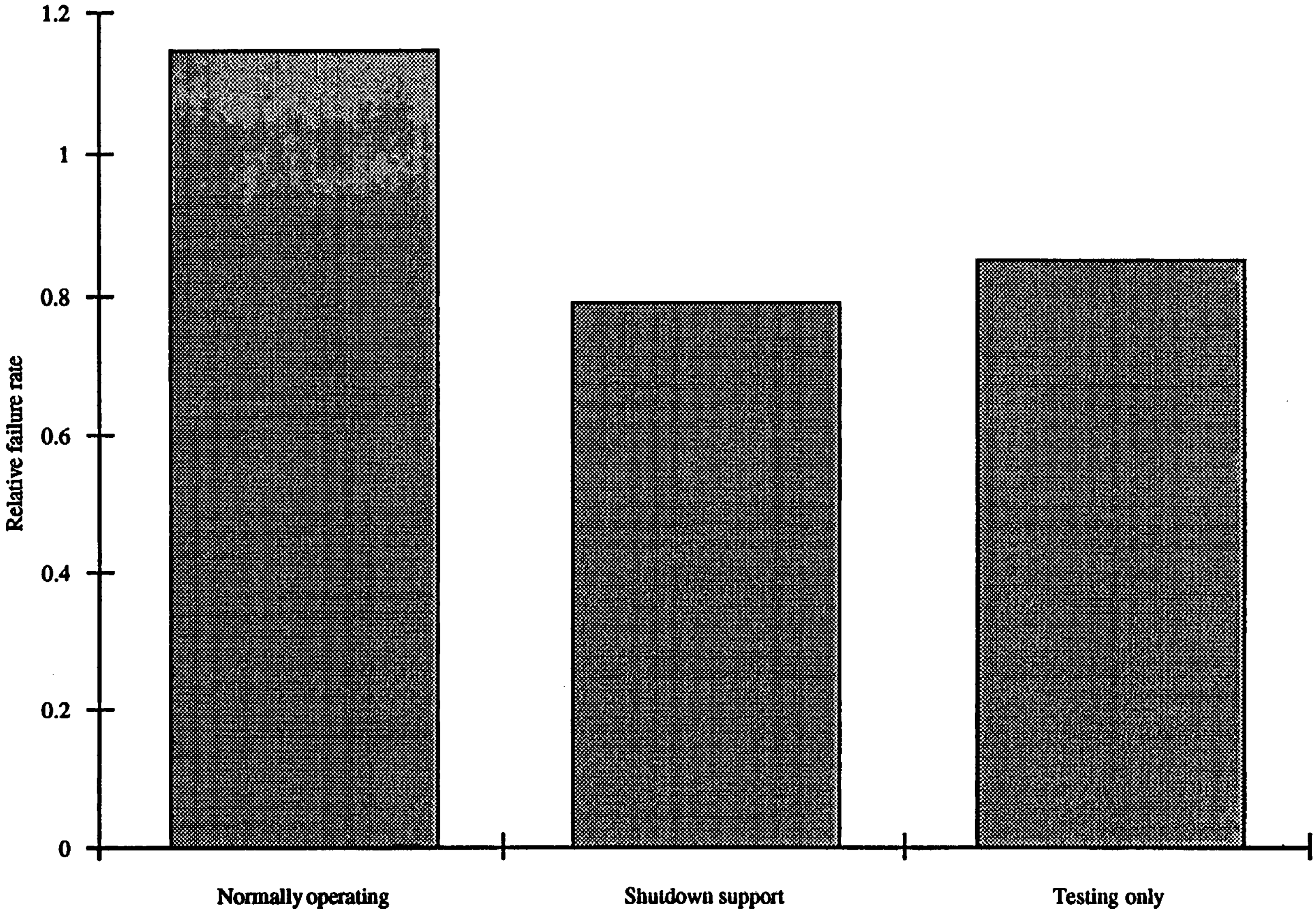


Figure A.6.1 Relative failure rate by system usage

ORNL-DWG 93-7394

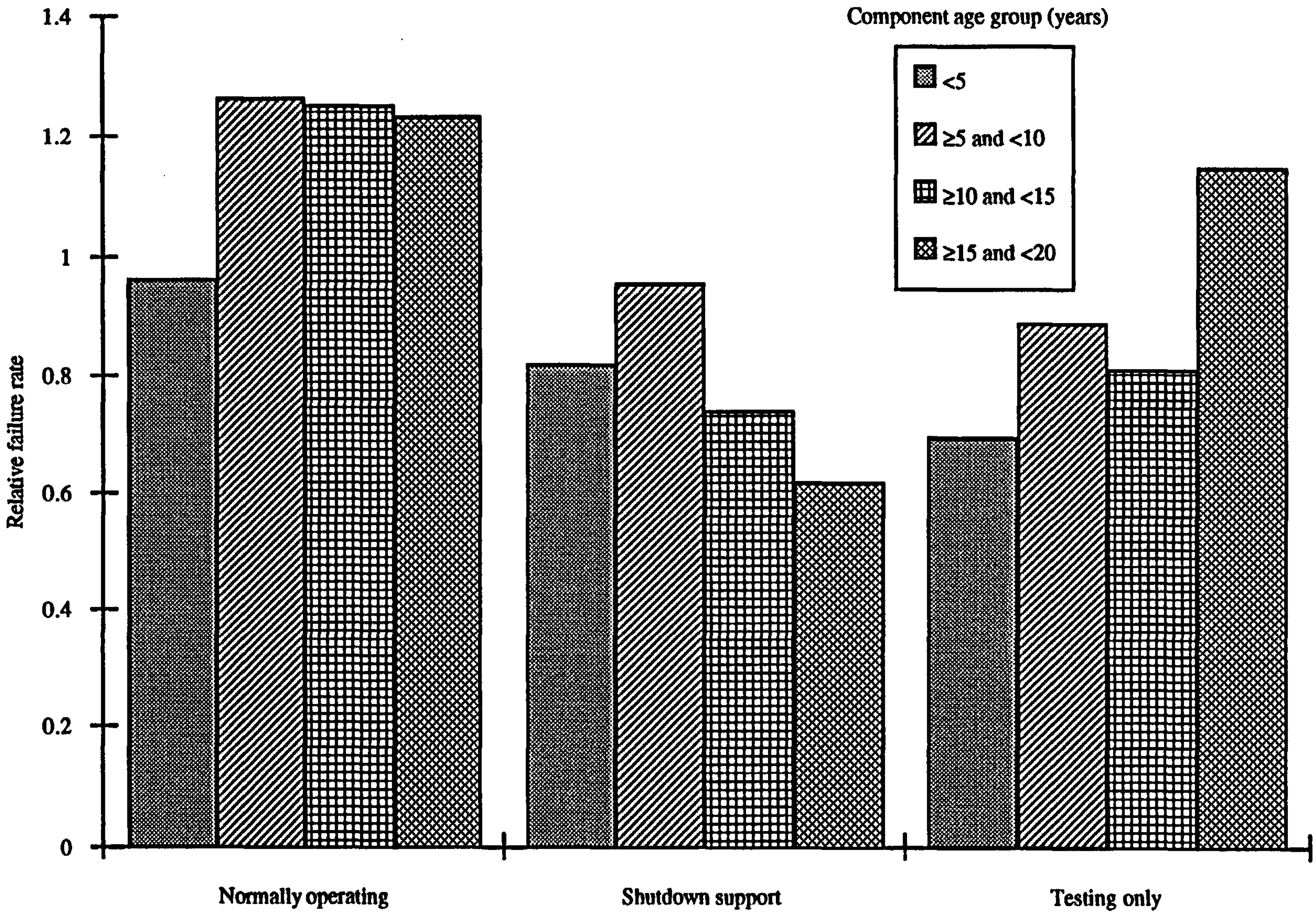


Figure A.6.2 Relative failure rate by system usage and valve age group

ORNL–DWG 93–7395

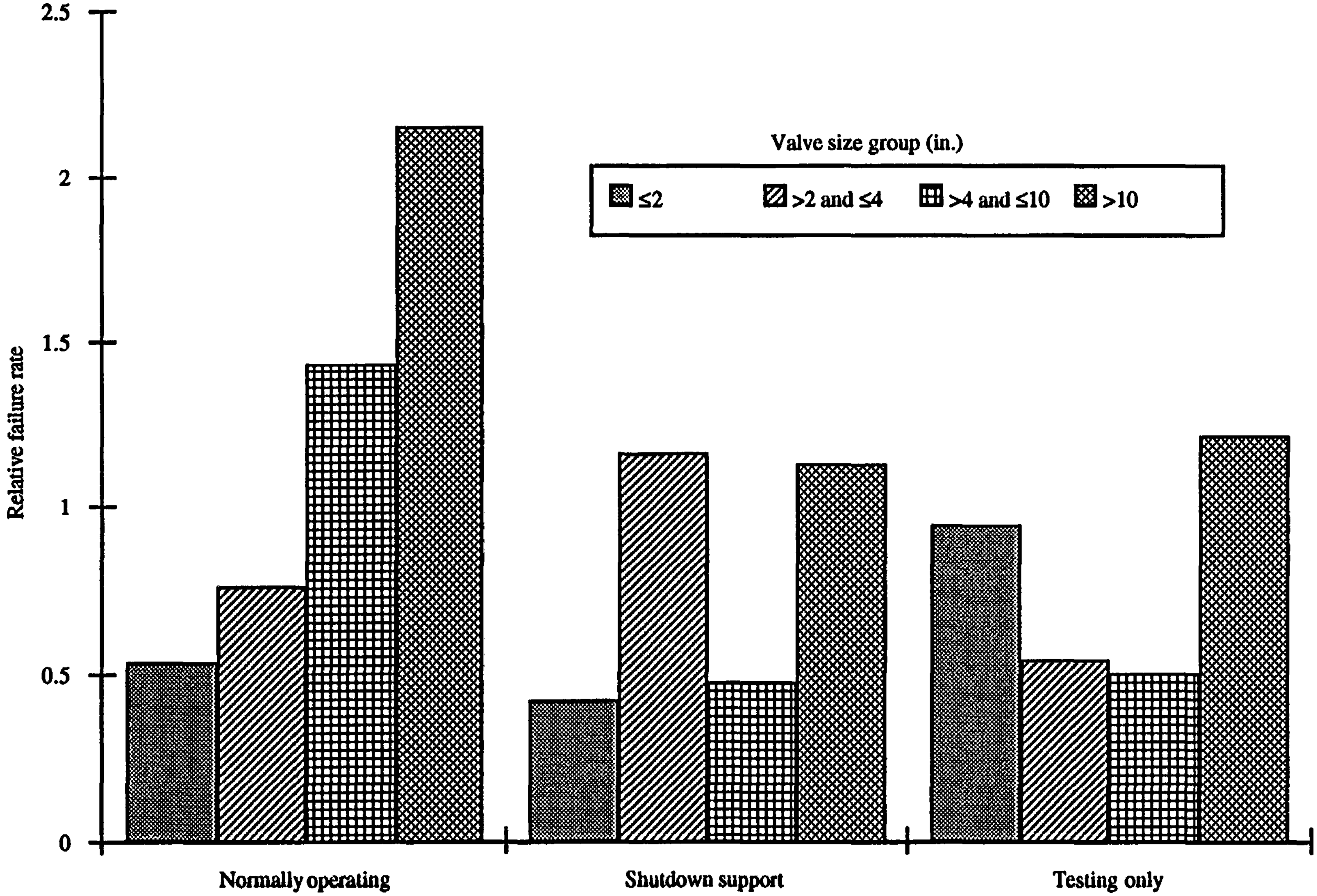


Figure A.6.3 Relative failure rate by system usage and valve size group

ORNL-DWG 93-7396

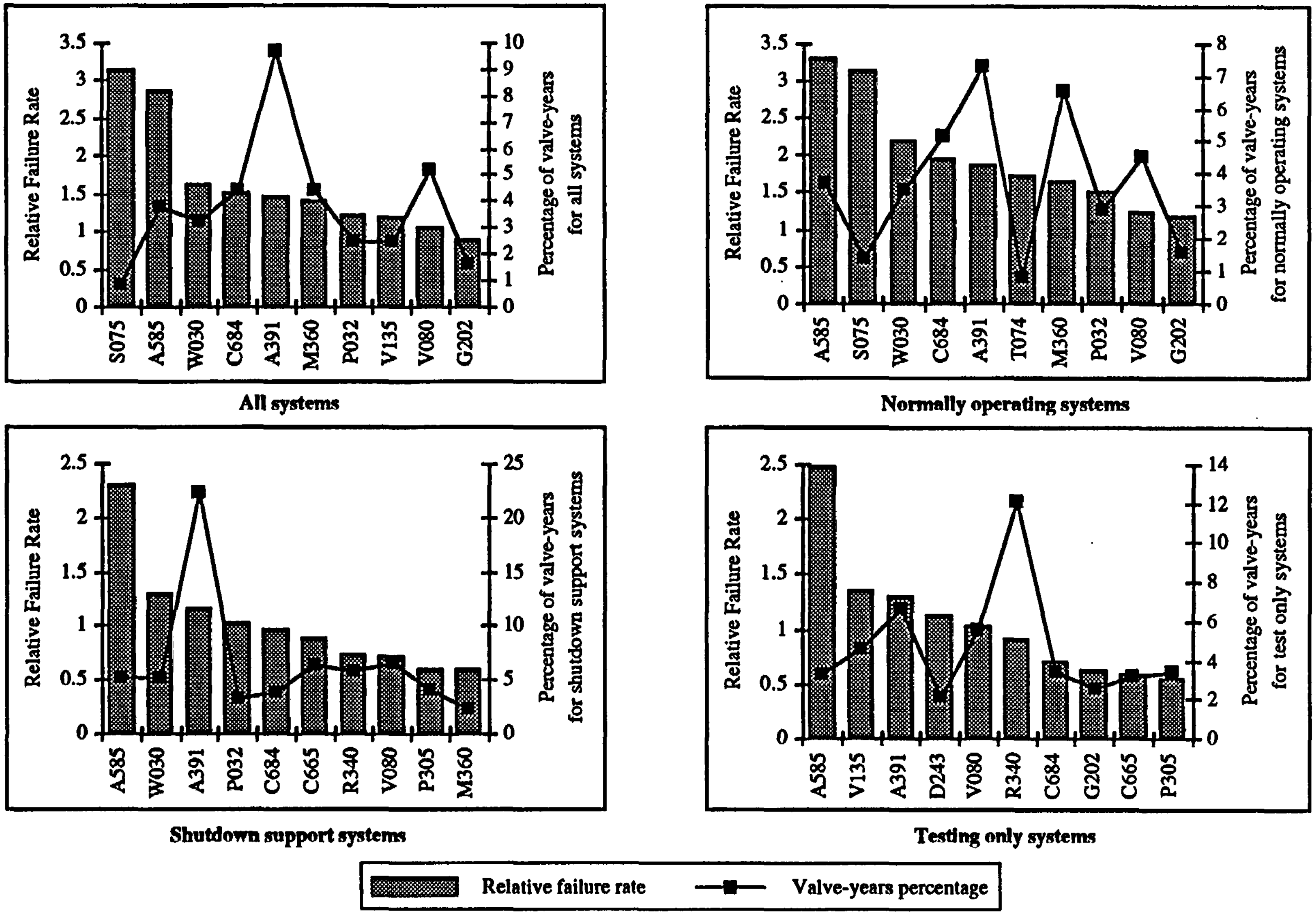


Figure A.6.4 Relative failure rate and portion of operating experience by system status for the ten manufacturers with the highest relative failure rate within the specified type of systems. Includes only manufacturers with ≥500 valve-years operation in the specified system status type (≥1000 valve-years for All systems chart)

ORNL–DWG 93–7397

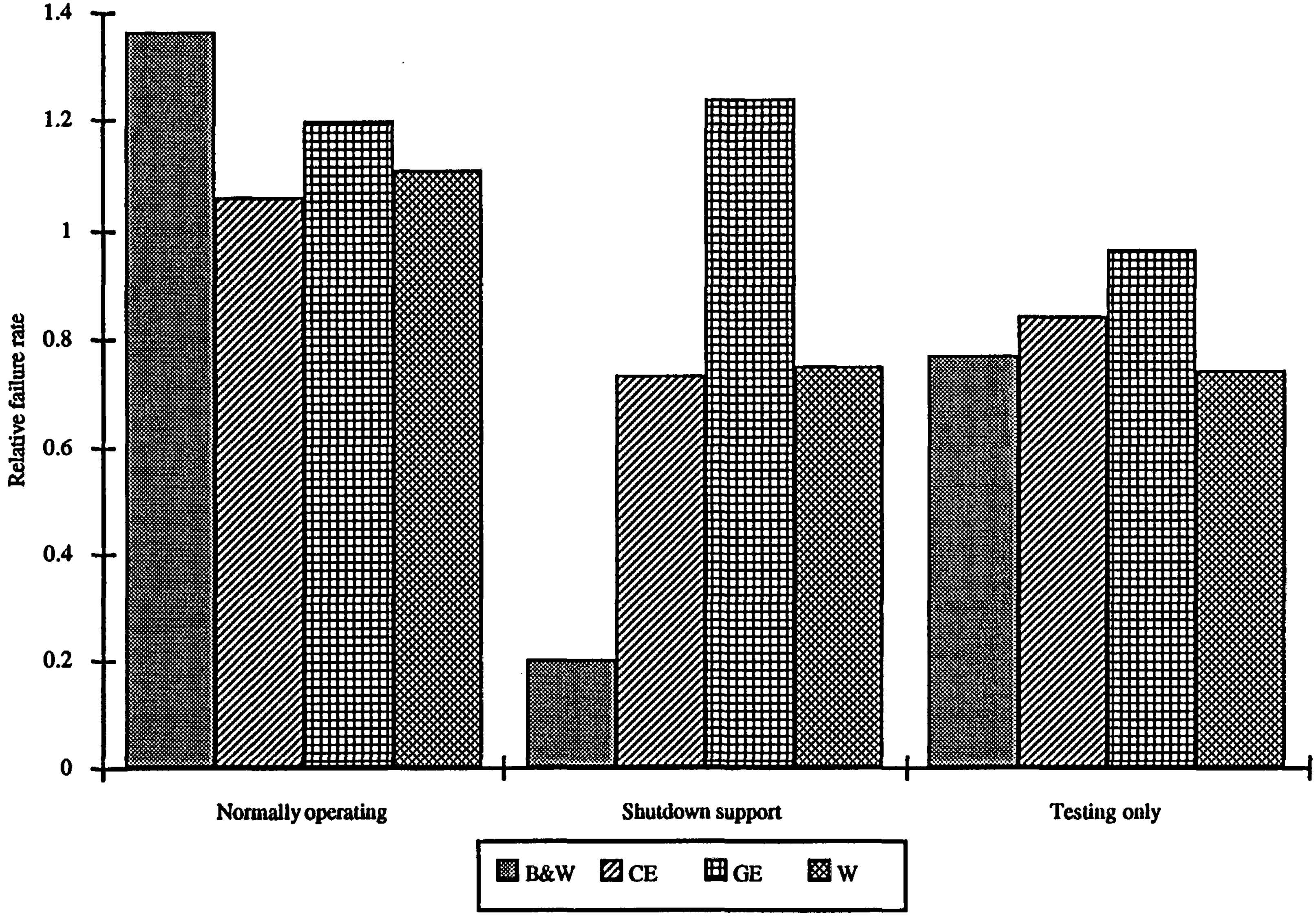


Figure A.6.5 Relative failure rate by system status and NSSS

ORNL-DWG 93-7398

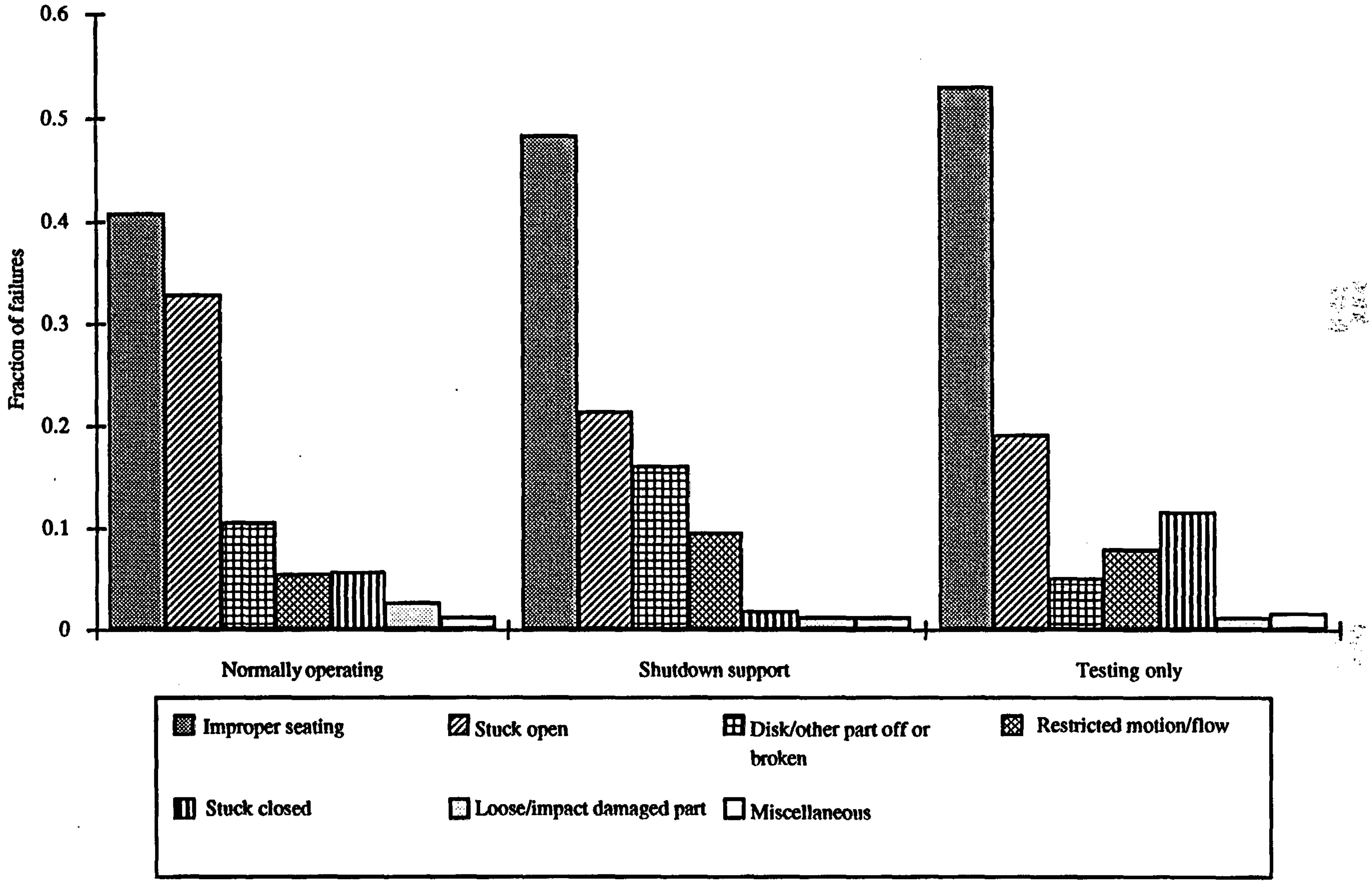


Figure A.6.6 Distribution of failures by system status and failure mode

ORNL-DWG 93-7399

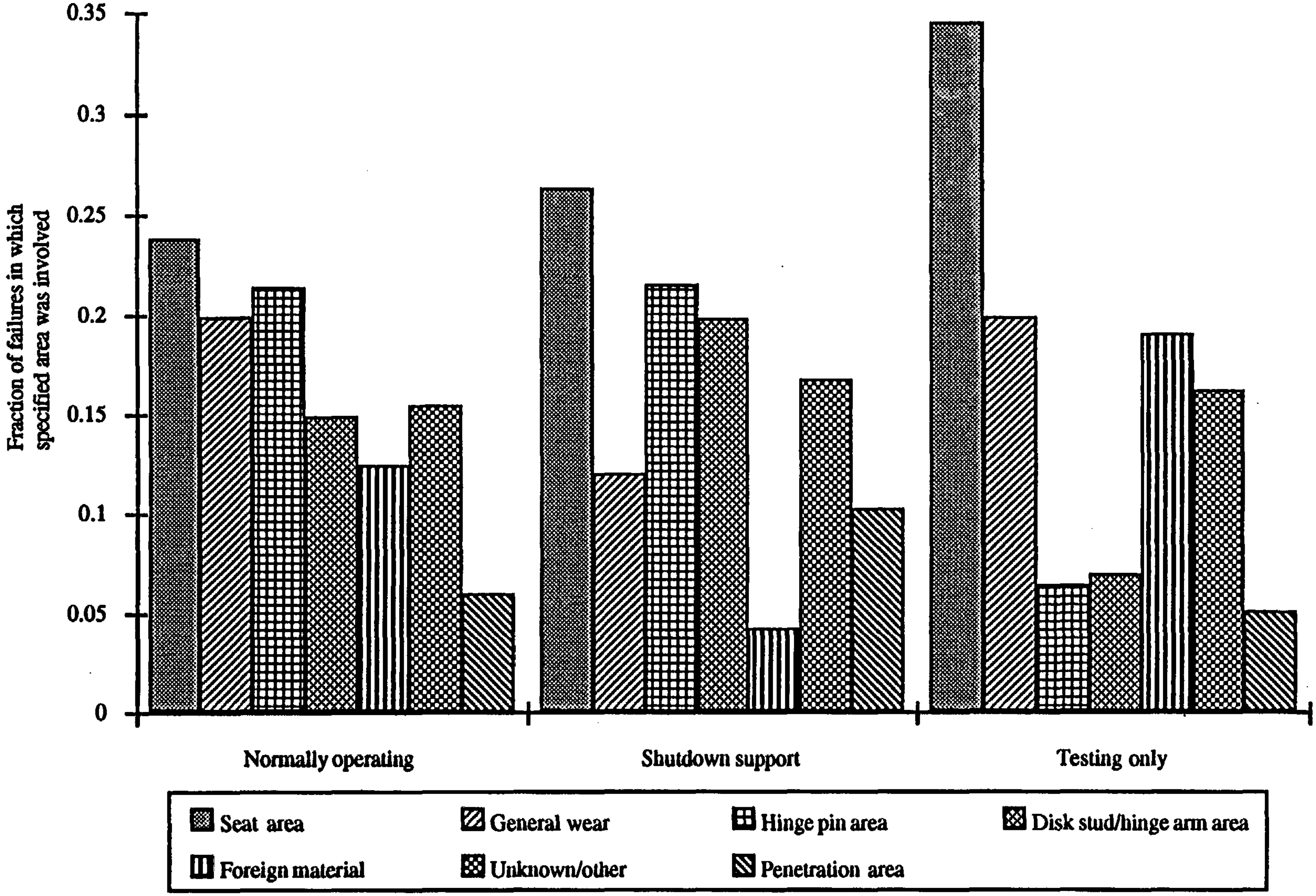
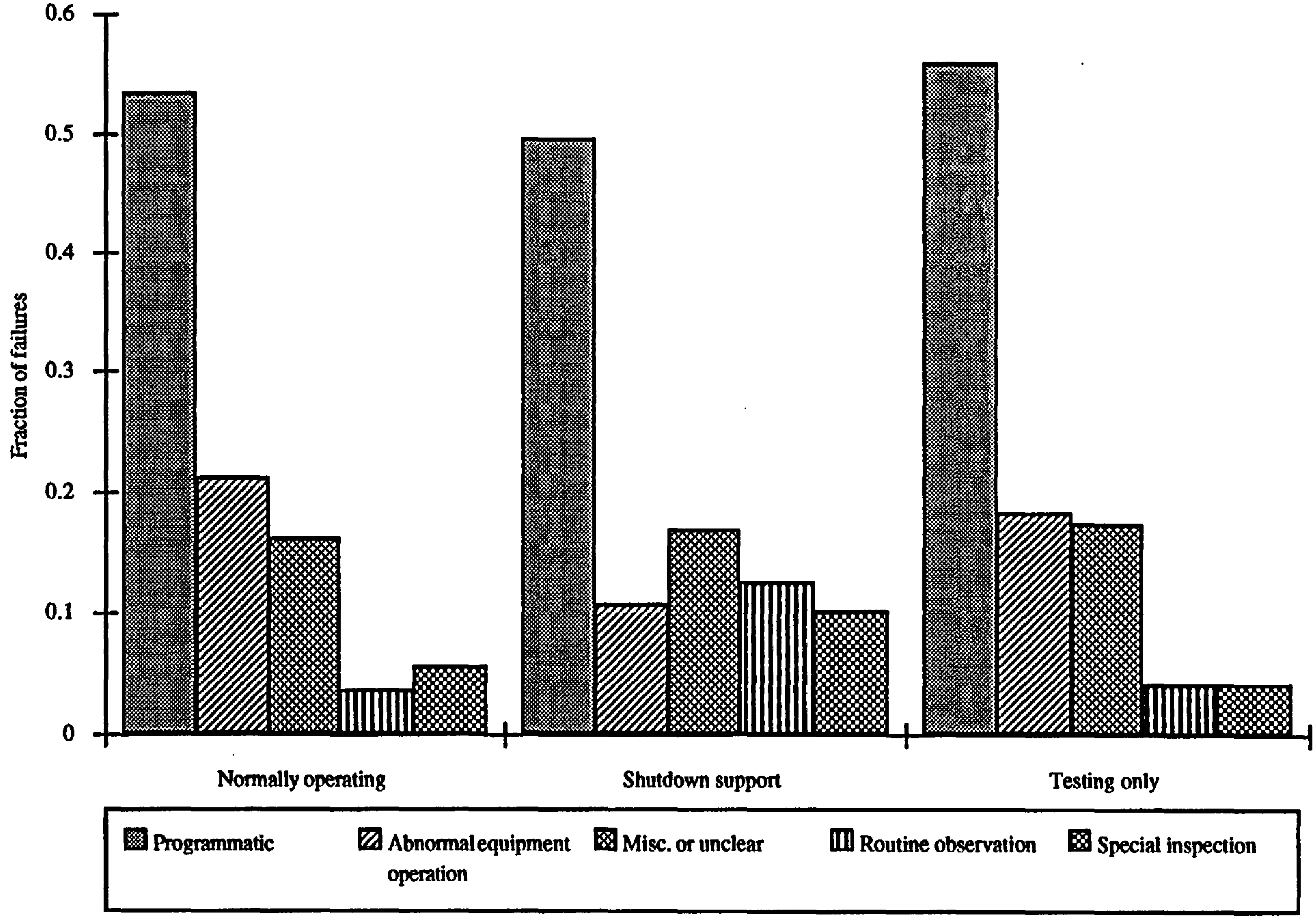


Figure A.6.7 Fraction of failures by system usage and failure area/source. Values shown are the fractions of failures in a particular system usage category in which the designated area was affected

ORNL–DWG 93–7400



A.6.8 Distribution of failures by general detection method for the three system usage categories

ORNL-DWG 93-7401

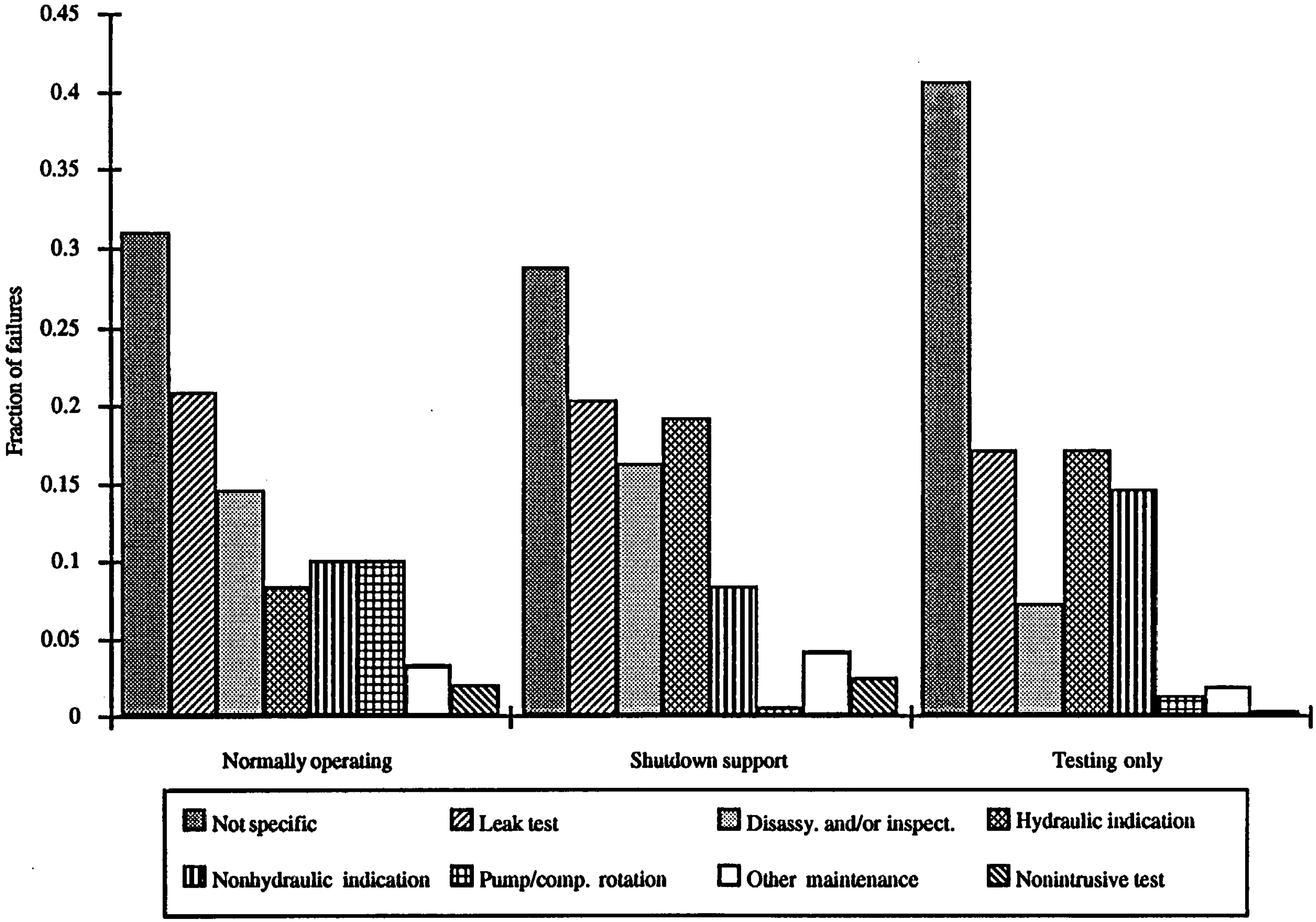


Figure A.6.9 Distribution of failures by specific method of detection for the three system usage categories

ORNL–DWG 93–7402

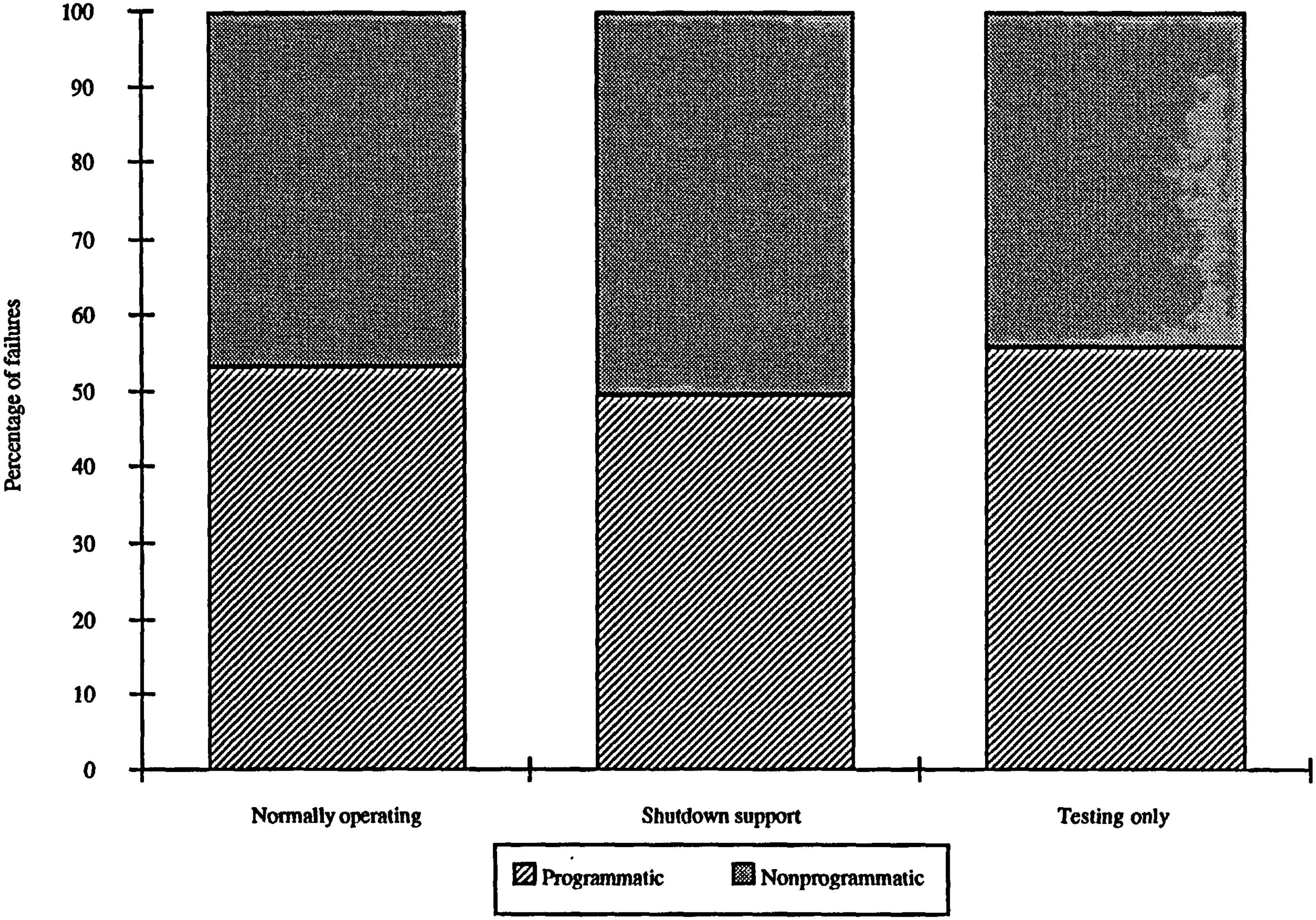


Figure A.6.10 Distribution of failures by system usage and general discovery process

ORNL–DWG 93–7403

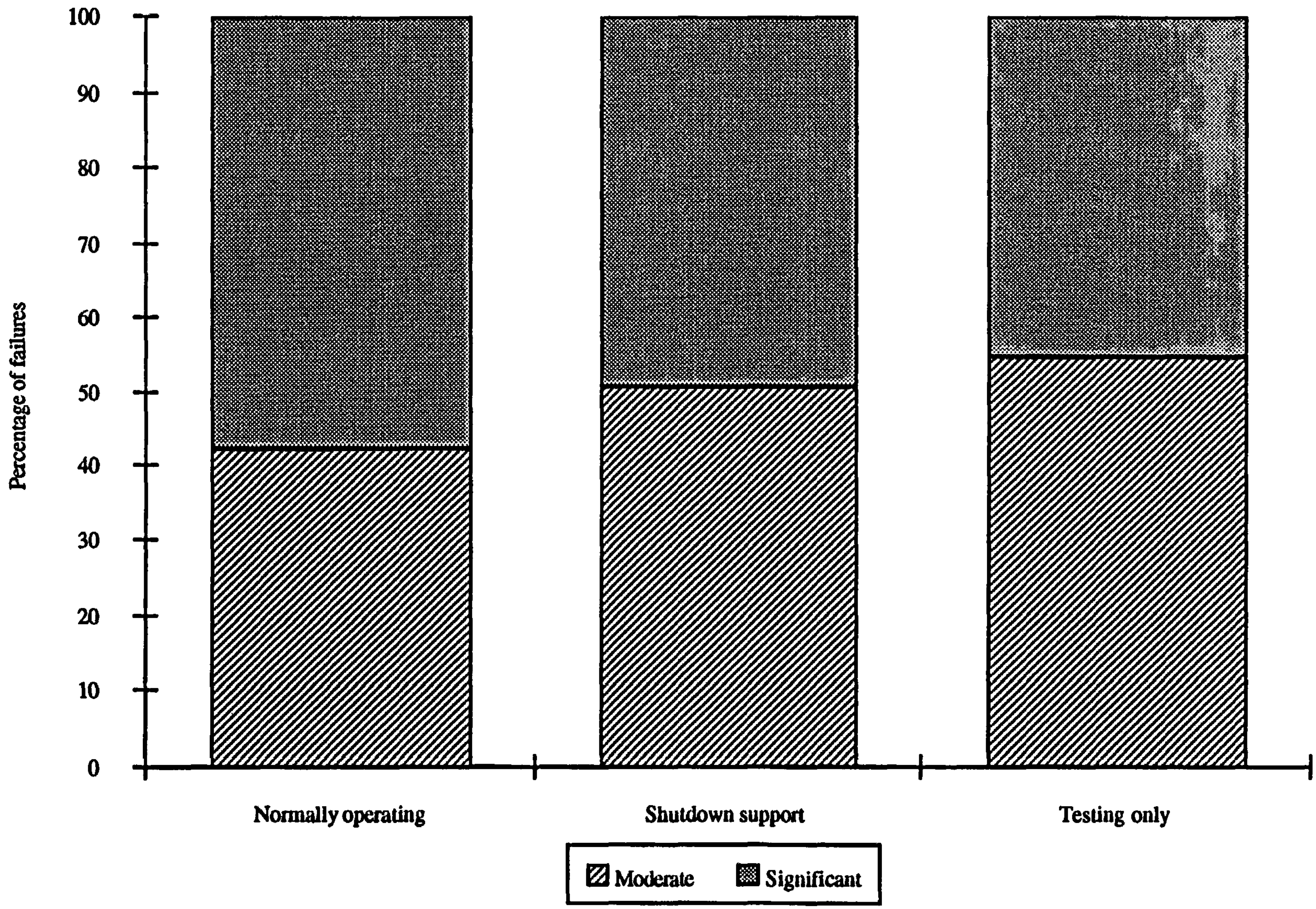


Figure A.6.11 Distribution of failures by system usage and extent of degradation

ORNL-DWG 93-7404

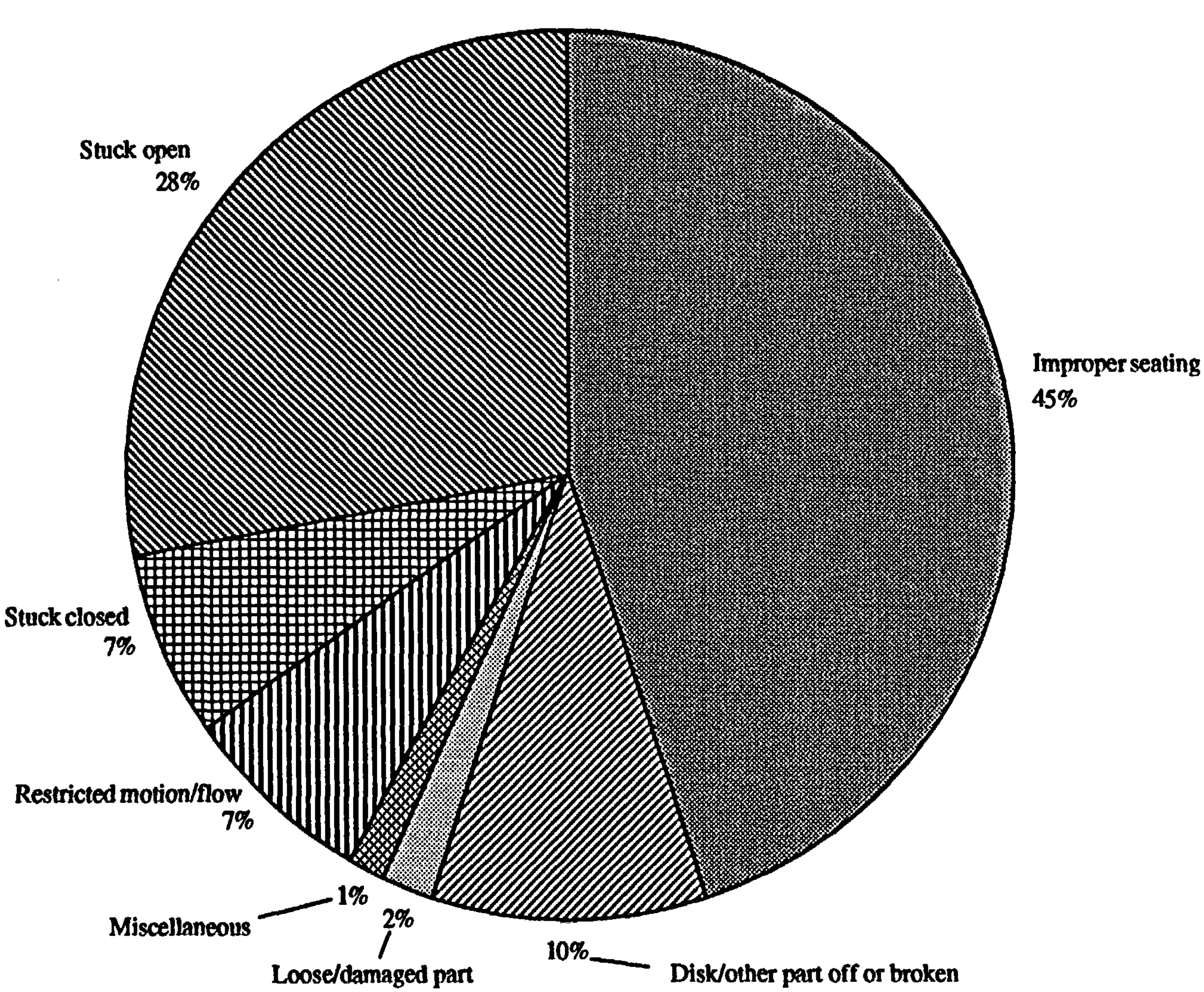


Figure A.7.1 Distribution of failures by failure mode

ORNL-DWG 93-7405

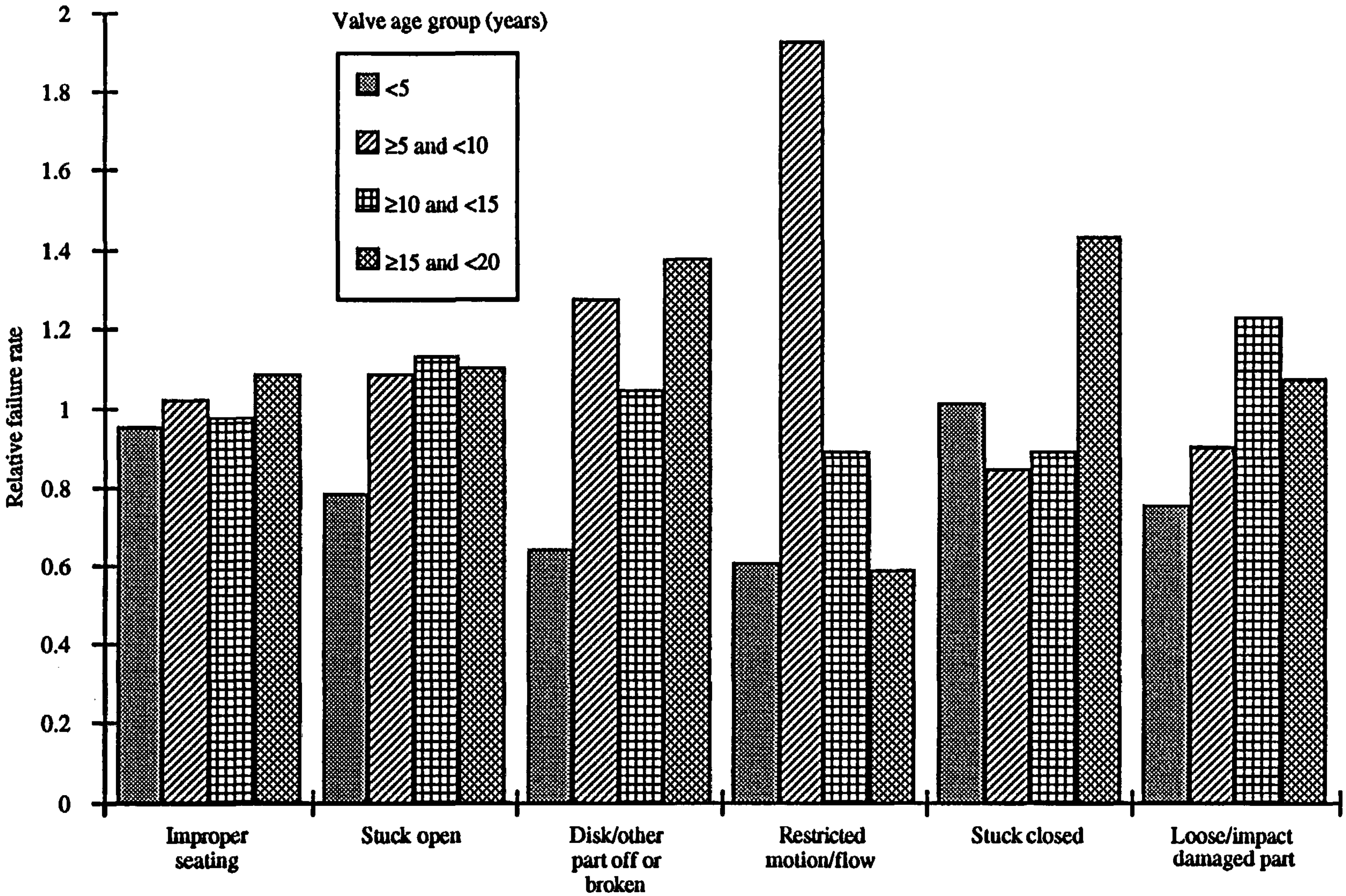


Figure A.7.2 Relative failure rate by failure mode and age group. Normalization structured such that the service weighted average failure rate for each failure mode is one

ORNL-DWG 93-7406

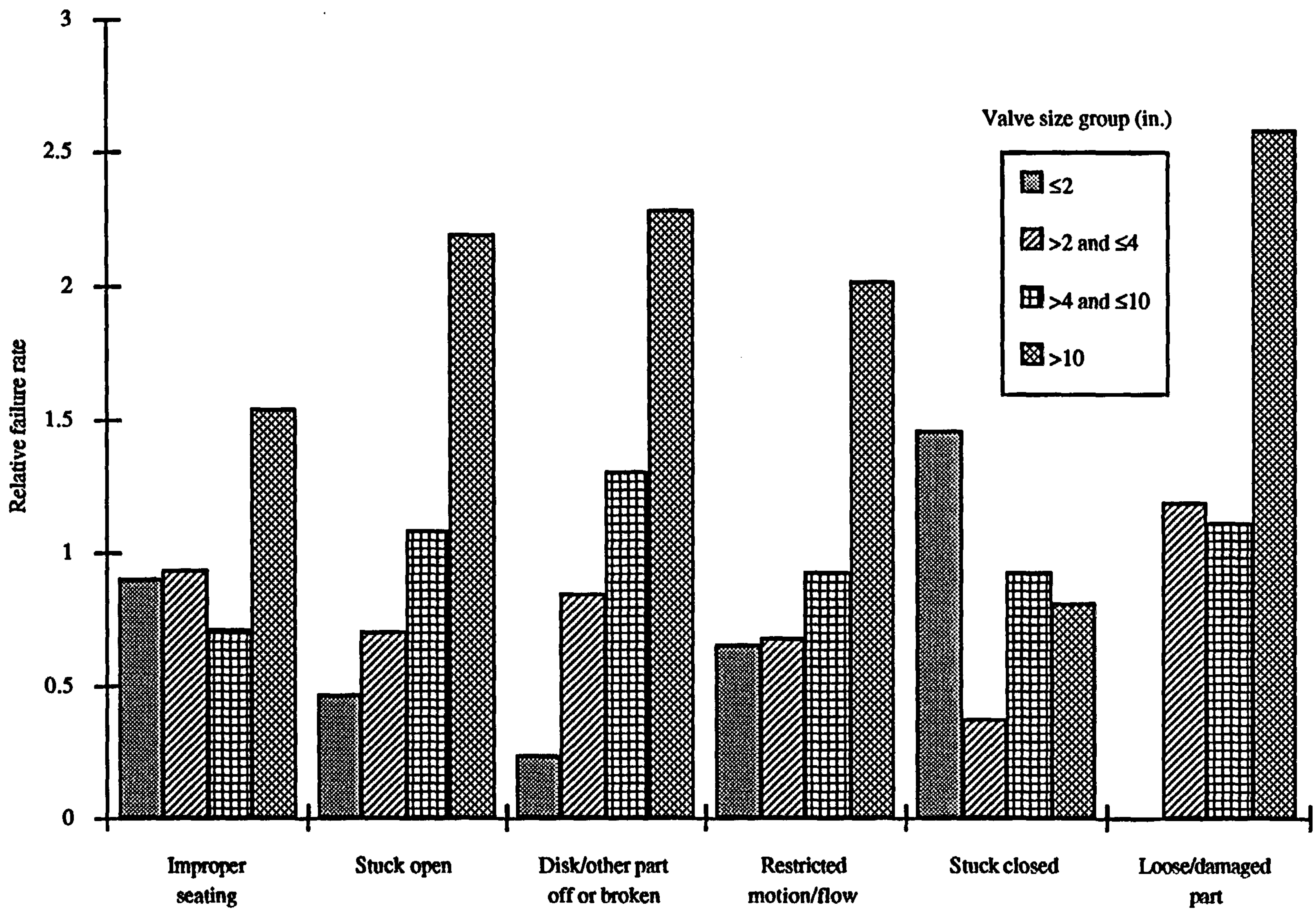


Figure A.7.3 Relative failure rate by failure mode and size group. Normalization structured such that the service weighted average failure rate for each failure mode is one

ORNL-DWG 93-7407

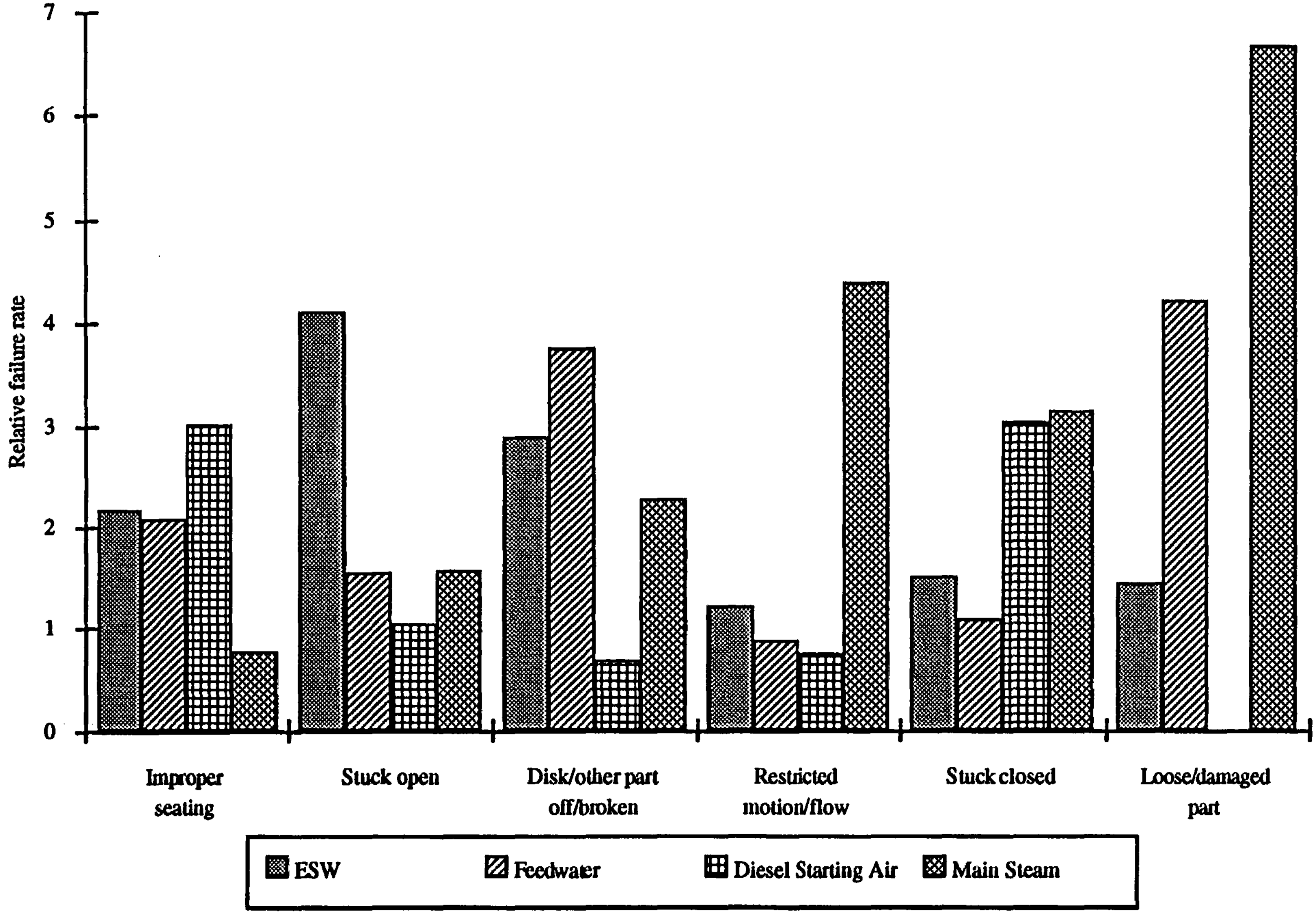


Figure A.7.4 Relative failure rate by failure mode for four systems with the highest overall failure rate. The rates indicated are based on a normalized failure rate of one for all systems within the designated failure mode. Thus, ESW valves were slightly more than twice as likely to have failed due to improper seating as the population as a whole

ORNL-DWG 93-7408

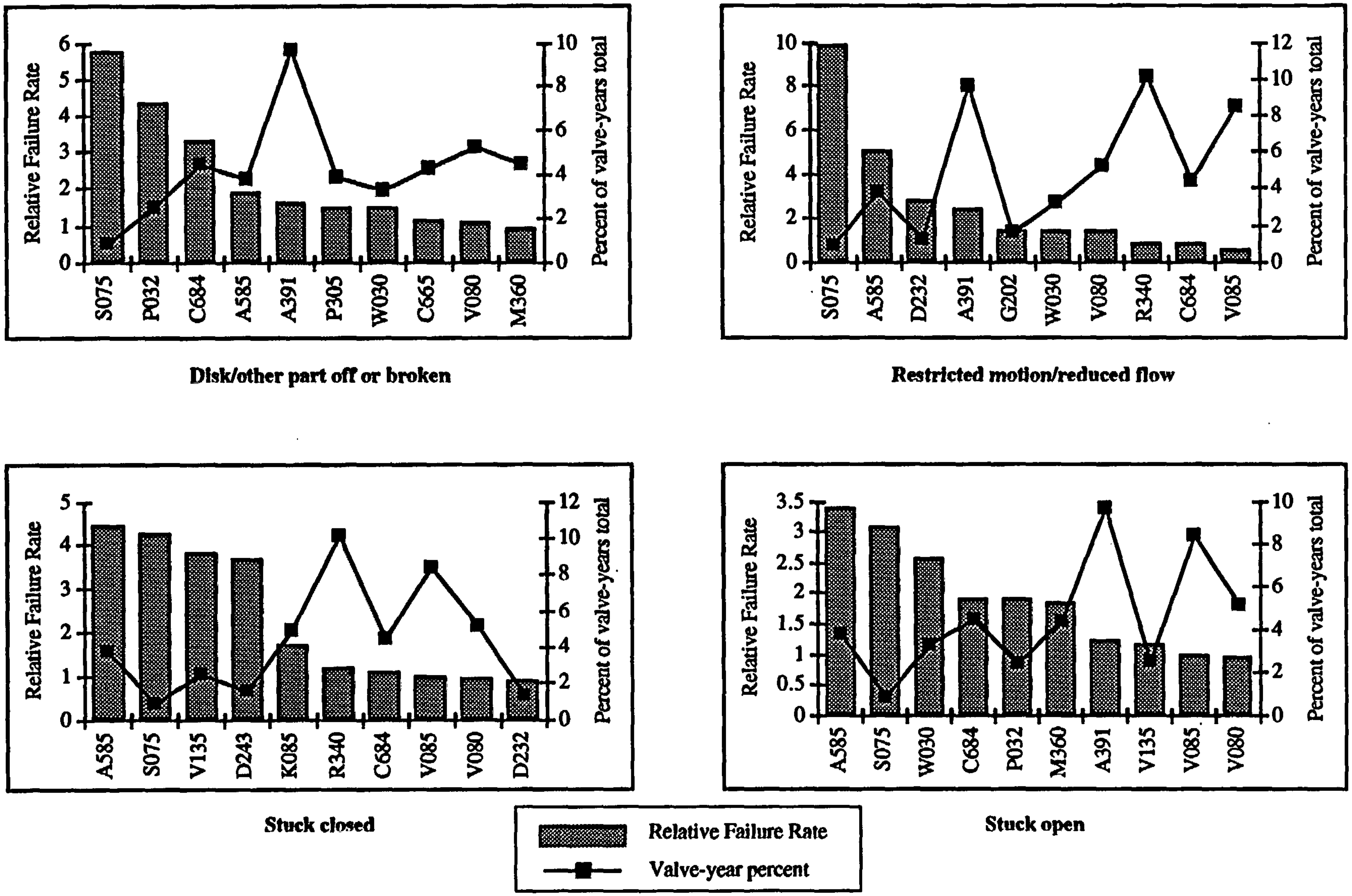


Figure A.7.5 **Relative failure rates and percentage of valve population service life for ten manufacturers for four failure modes. The charts are sorted by relative failure rate within the particular failure mode**

ORNL–DWG 93–7409

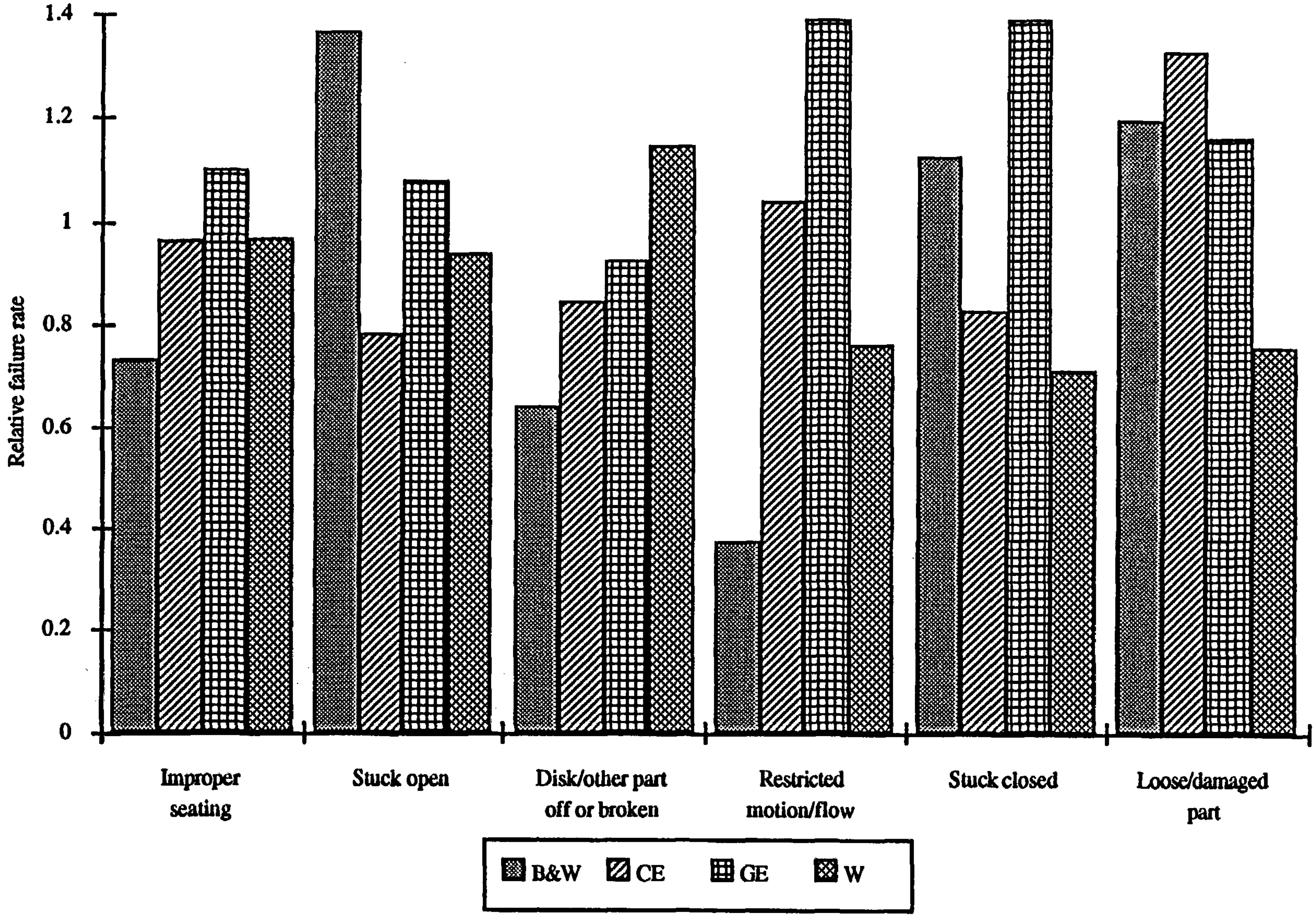


Figure A.7.6 **Relative failure rate by failure mode and NSSS. The rates shown indicate the relative failure rates by NSSS within the designated failure mode. The valve-years weighted average of the values for any failure mode category equals one**

ORNL-DWG 93-7410

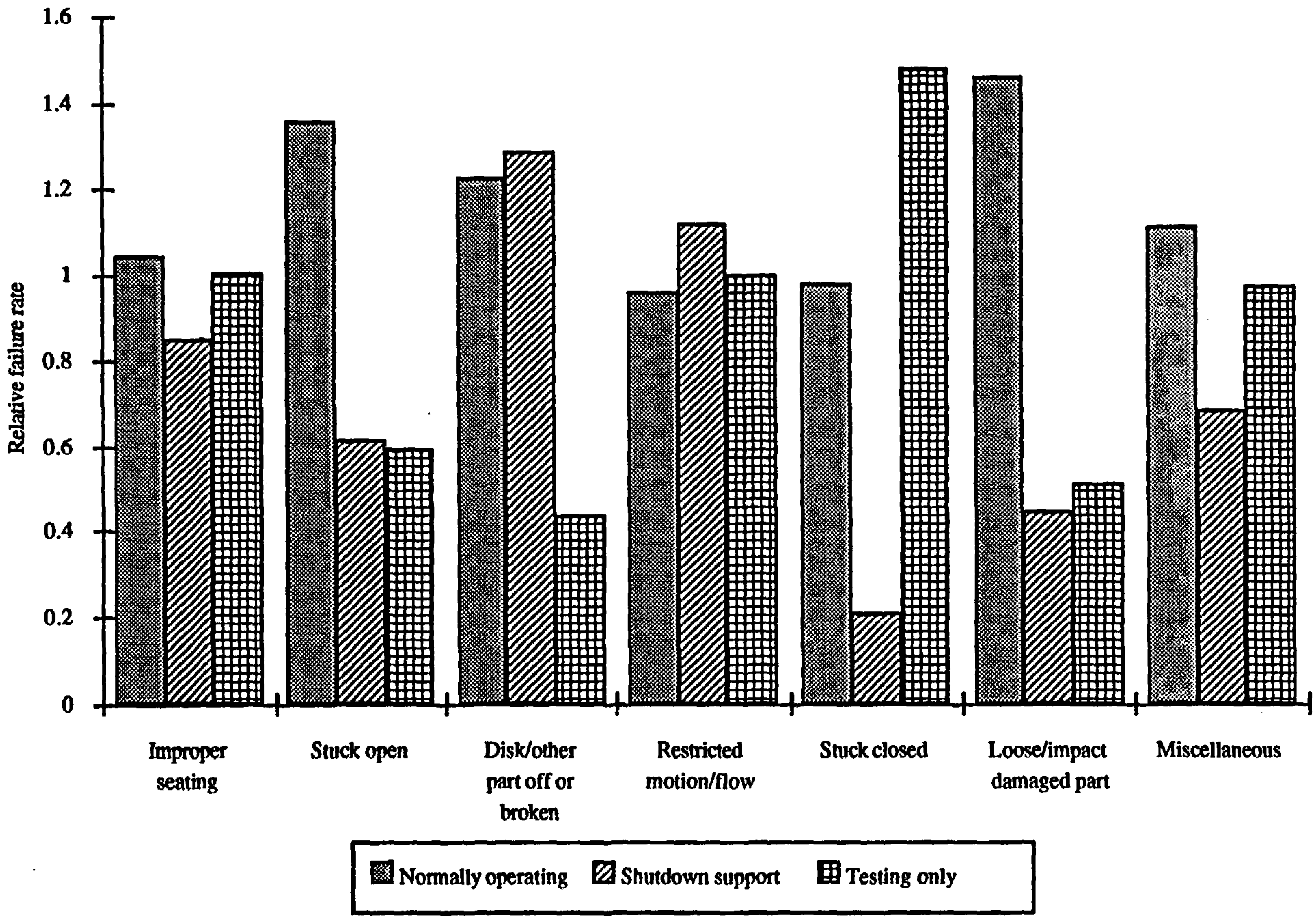


Figure A.7.7 Relative failure rate by failure mode and system status. The valve-years weighted average of the values for any failure mode category equals one

ORNL-DWG 93-7411

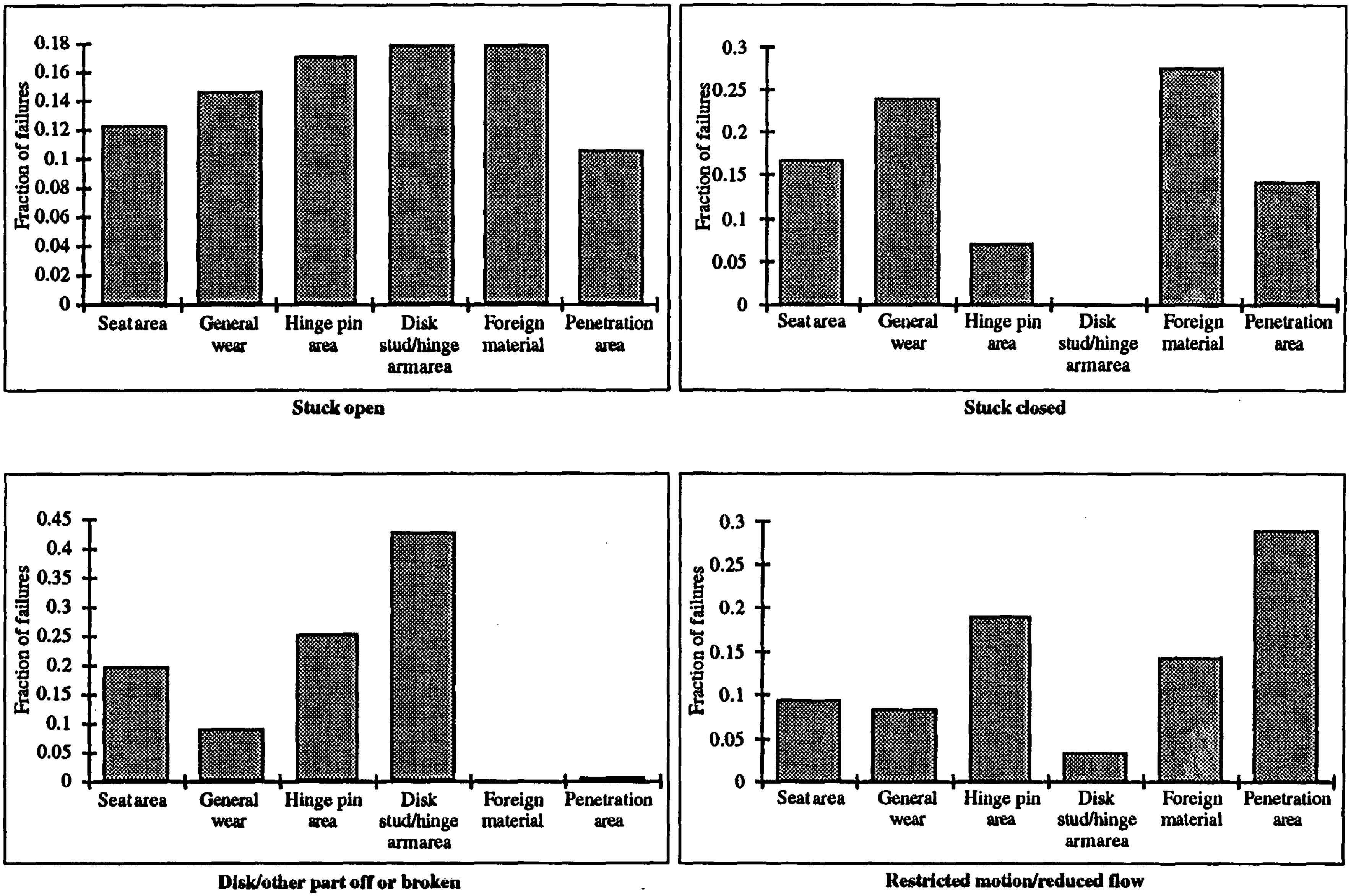


Figure A.7.8 Fraction of failures for selected failure modes in which selected areas were affected. Not all failure modes and failure areas shown

ORNL-DWG 93-7412

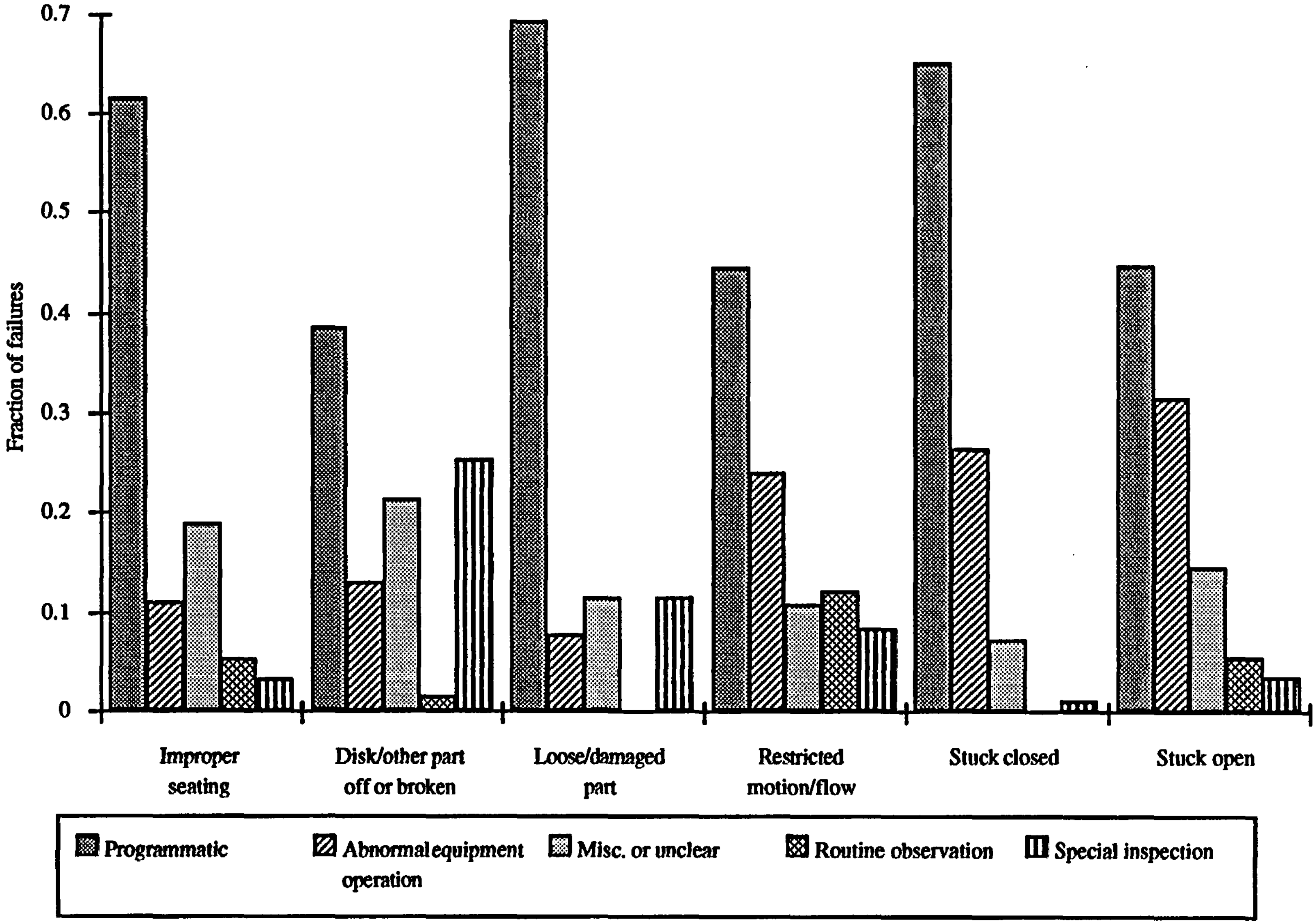


Figure A.7.9 Distribution of selected failure modes by general detection method

ORNL–DWG 93–7413

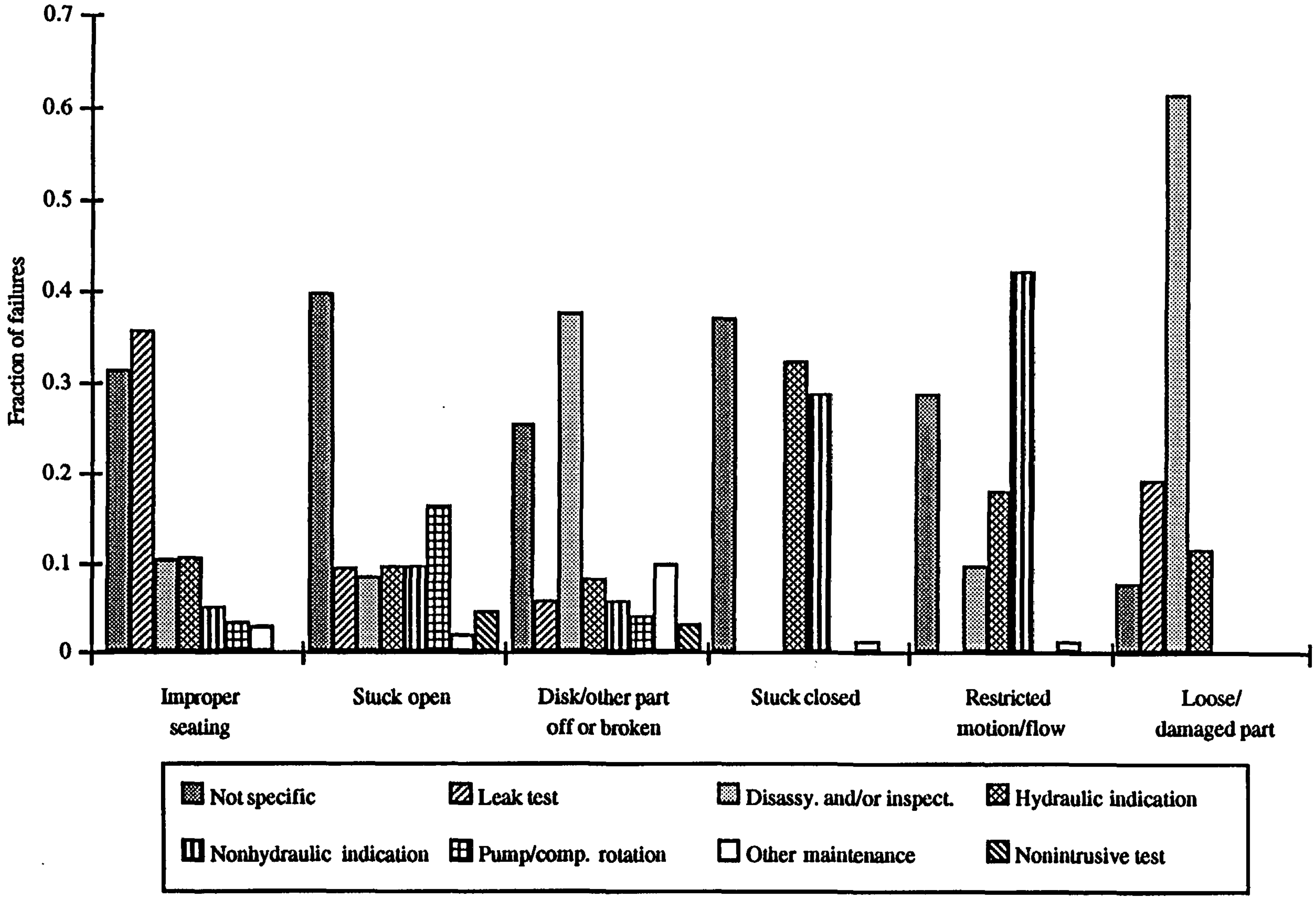


Figure A.7.10 Fraction of failures for selected failure modes by specific detection method

ORNL-DWG 93-7414

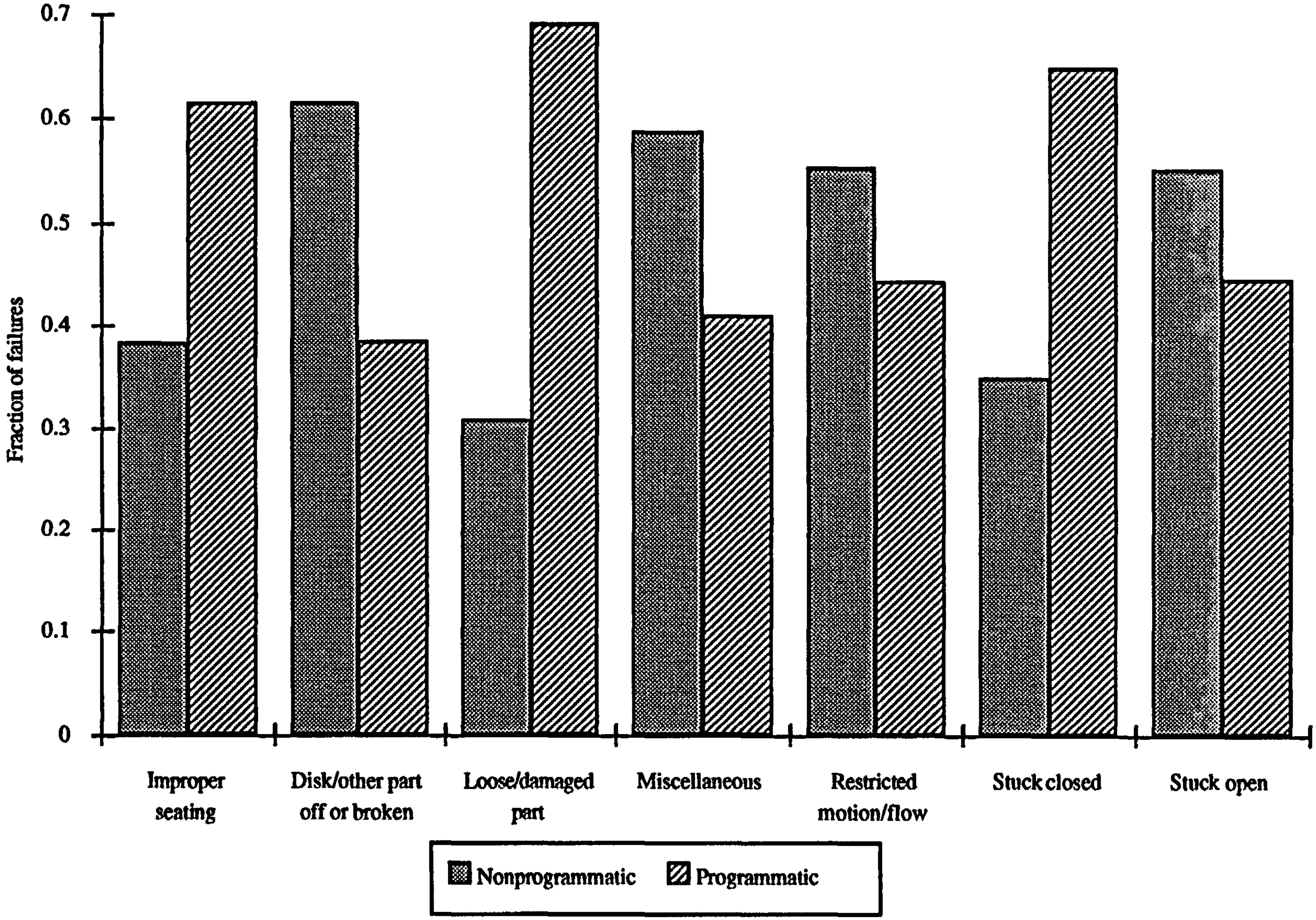


Figure A.7.11 Distribution of failures by general discovery process and failure mode

ORNL–DWG 93–7415

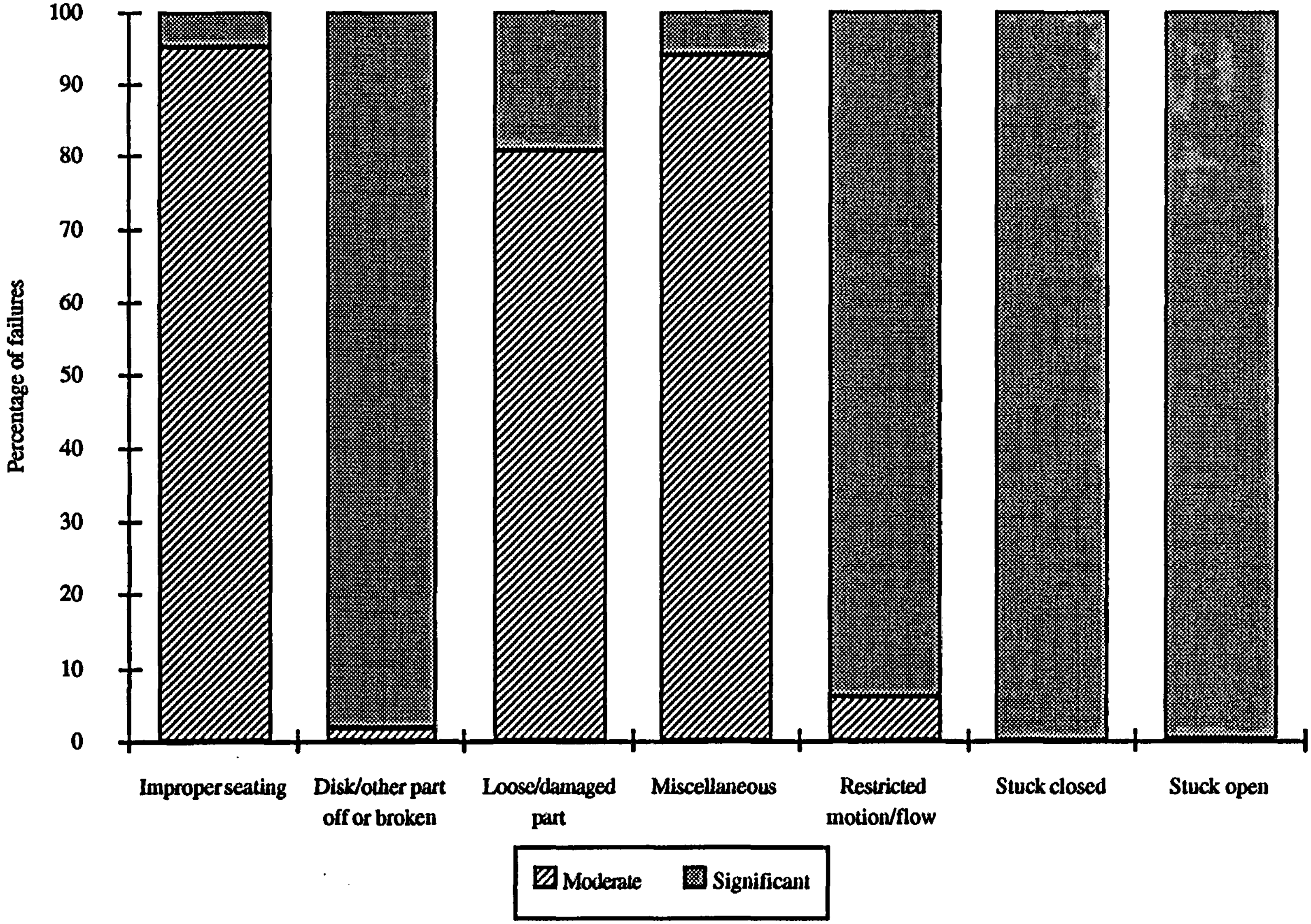


Figure A.7.12 Distribution of failures by failure mode and extent of degradation

ORNL–DWG 93–7416

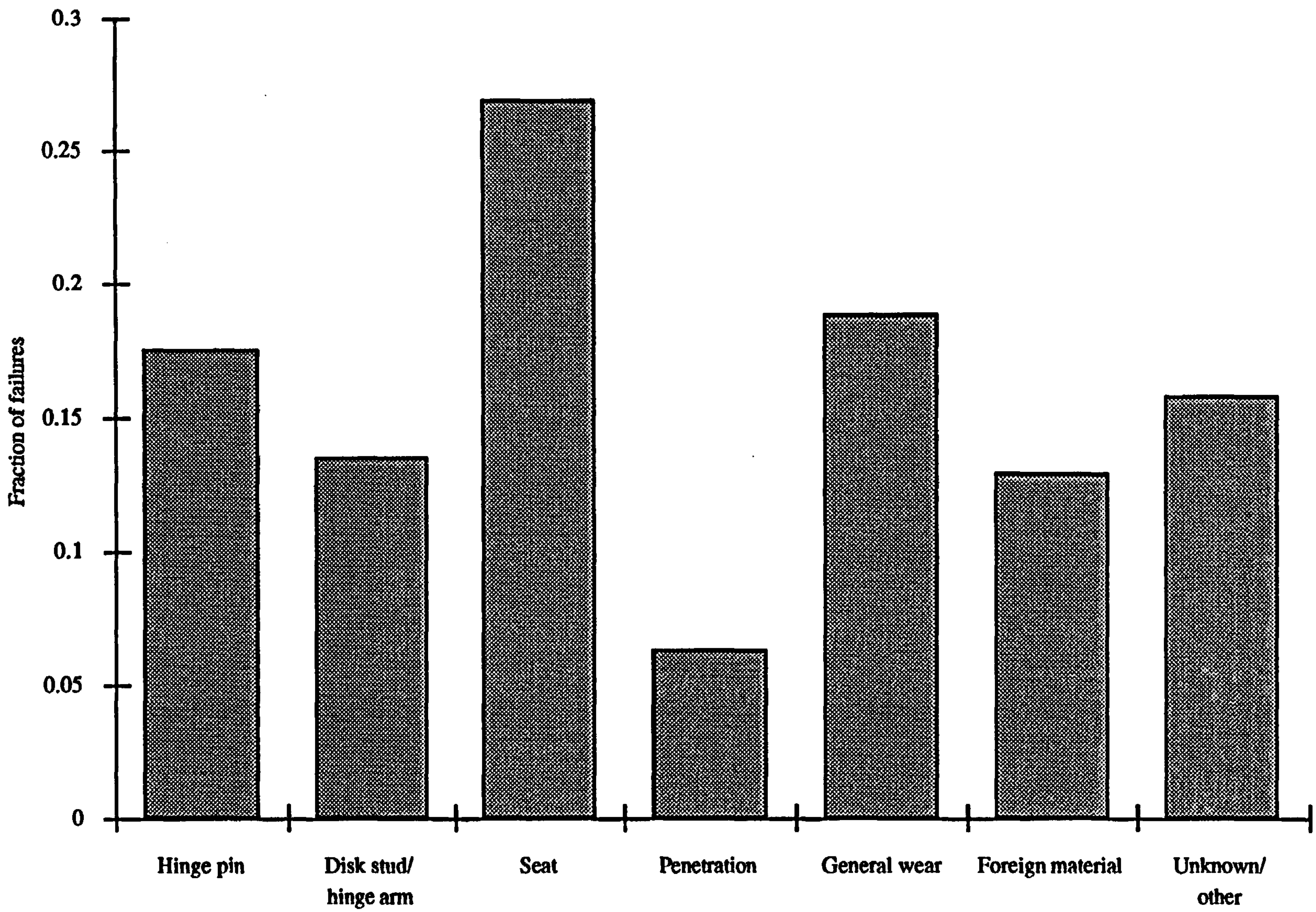


Figure A.8.1 Fraction of failures affecting designated areas. The sum of the fractions exceeds one because some failures affect more than one area

ORNL–DWG 93–7417

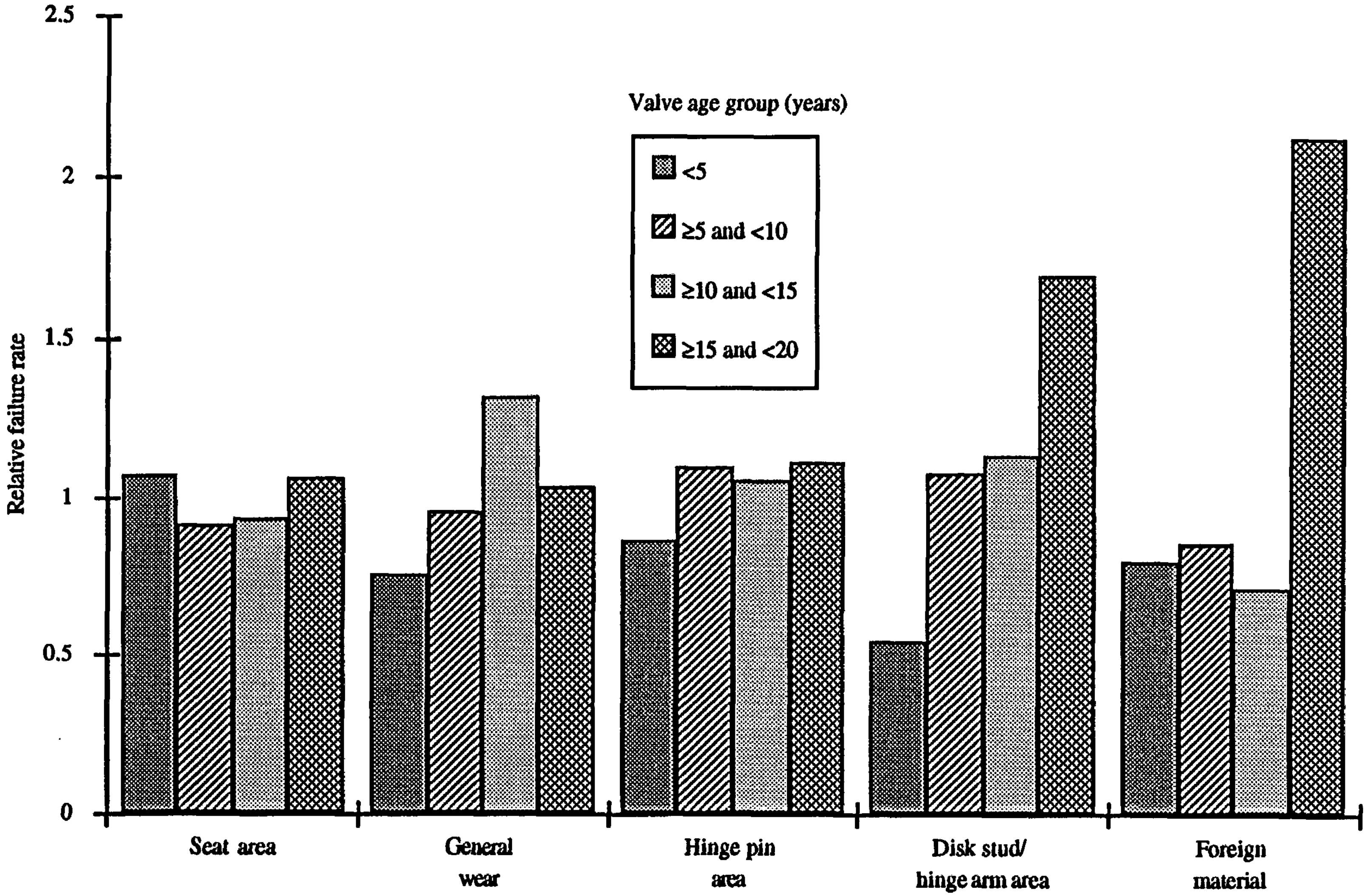


Figure A.8.2 Relative failure rate by failure area and age group for selected failure areas/causes. Normalization structured such that the service weighted average failure rate for each failure area for all age groups combined is one

ORNL-DWG 93-7418

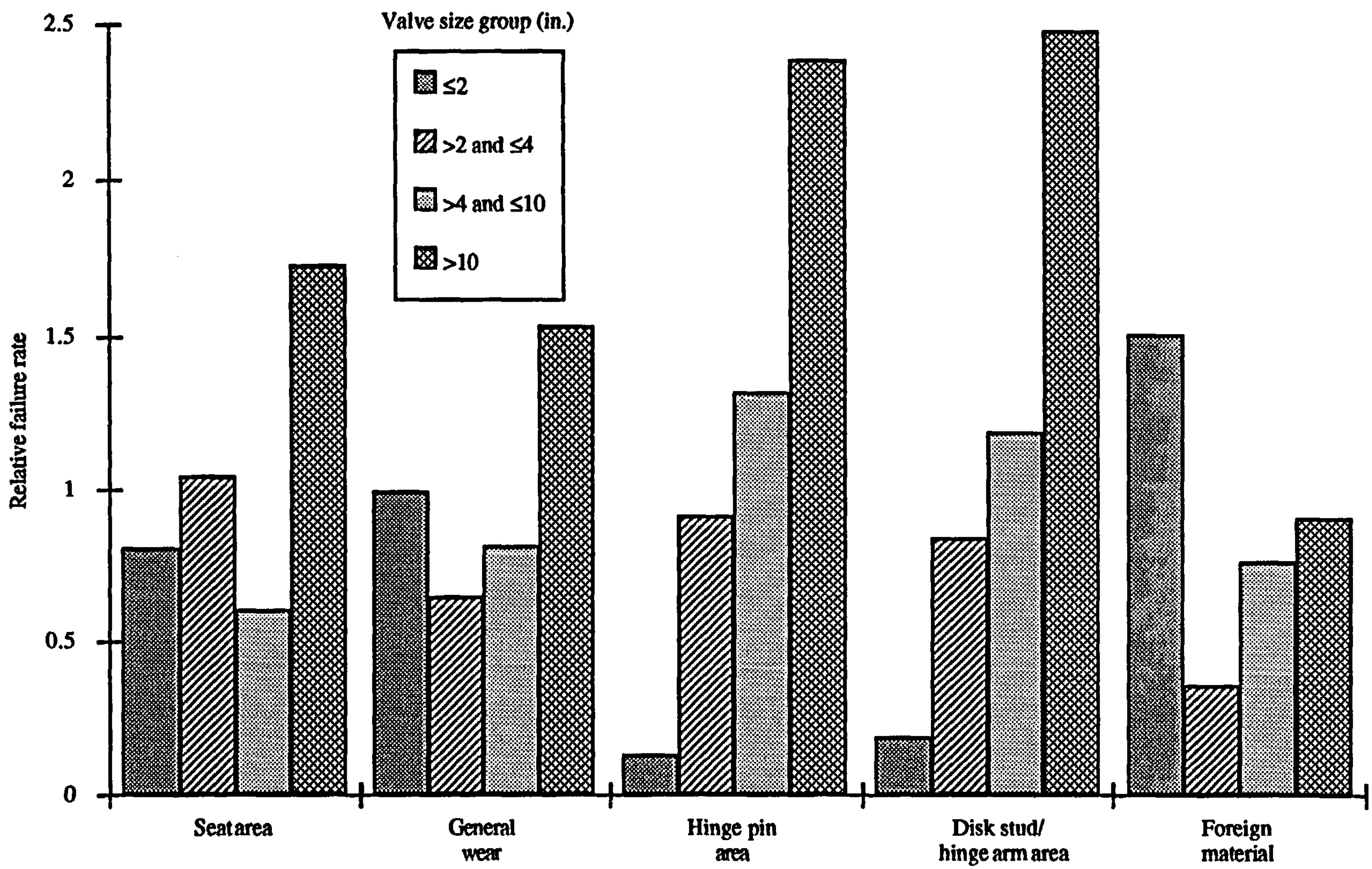


Figure A.8.3 Relative failure rate by failure area and valve size group for selected failure areas/causes. Normalization structured such that the service weighted average failure rate for each failure area for all size groups combined is one

ORNL-DWG 93-7419

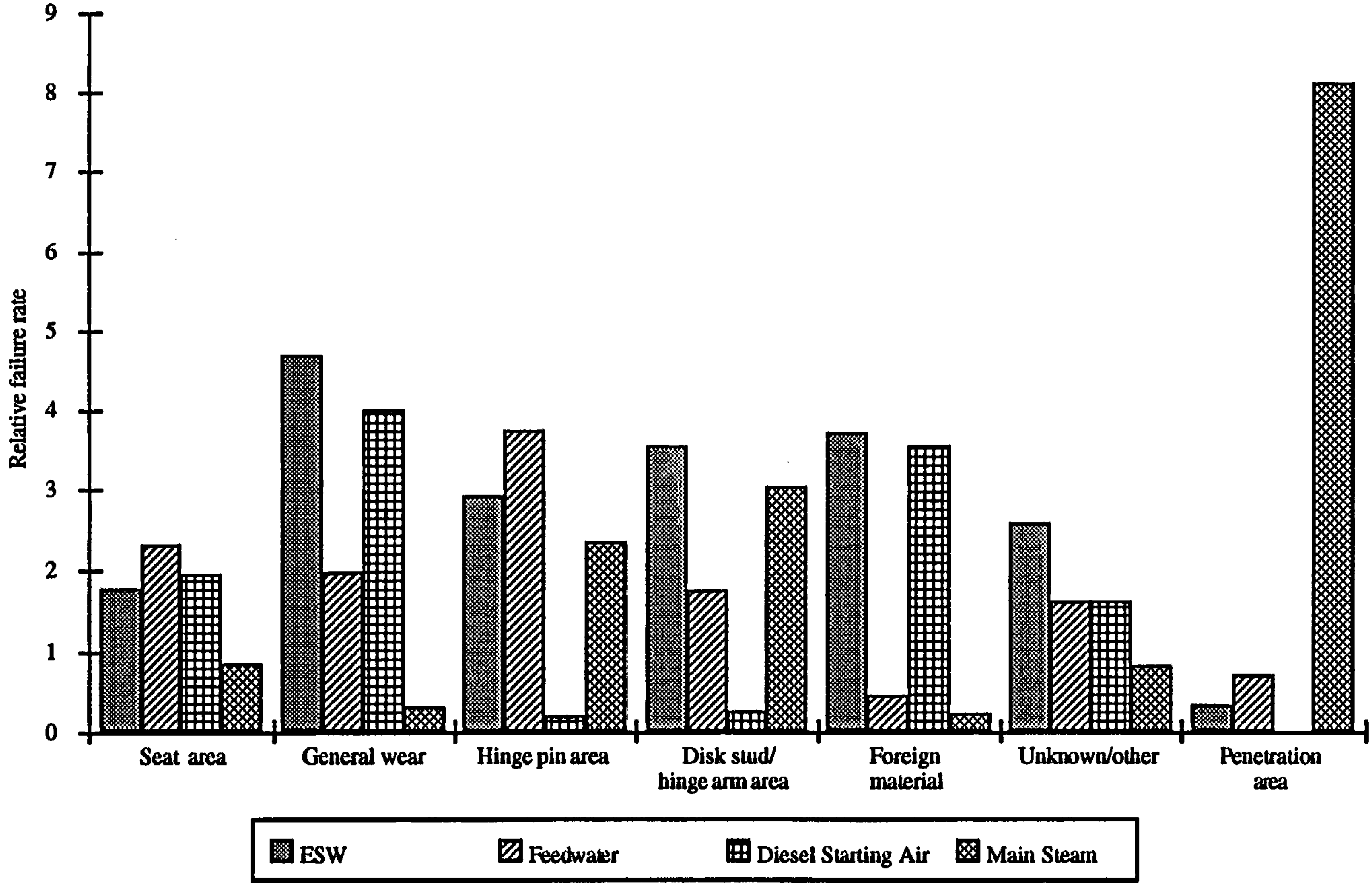


Figure A.8.4 Relative failure rate by failure area for four systems with the highest overall failure rate. The rates indicated are based on a normalized failure rate of one for all systems for the designated failure area. For example, ESW valves were about 3.5 times as likely to have disk stud/hinge arm area degradation as was the valve population as a whole

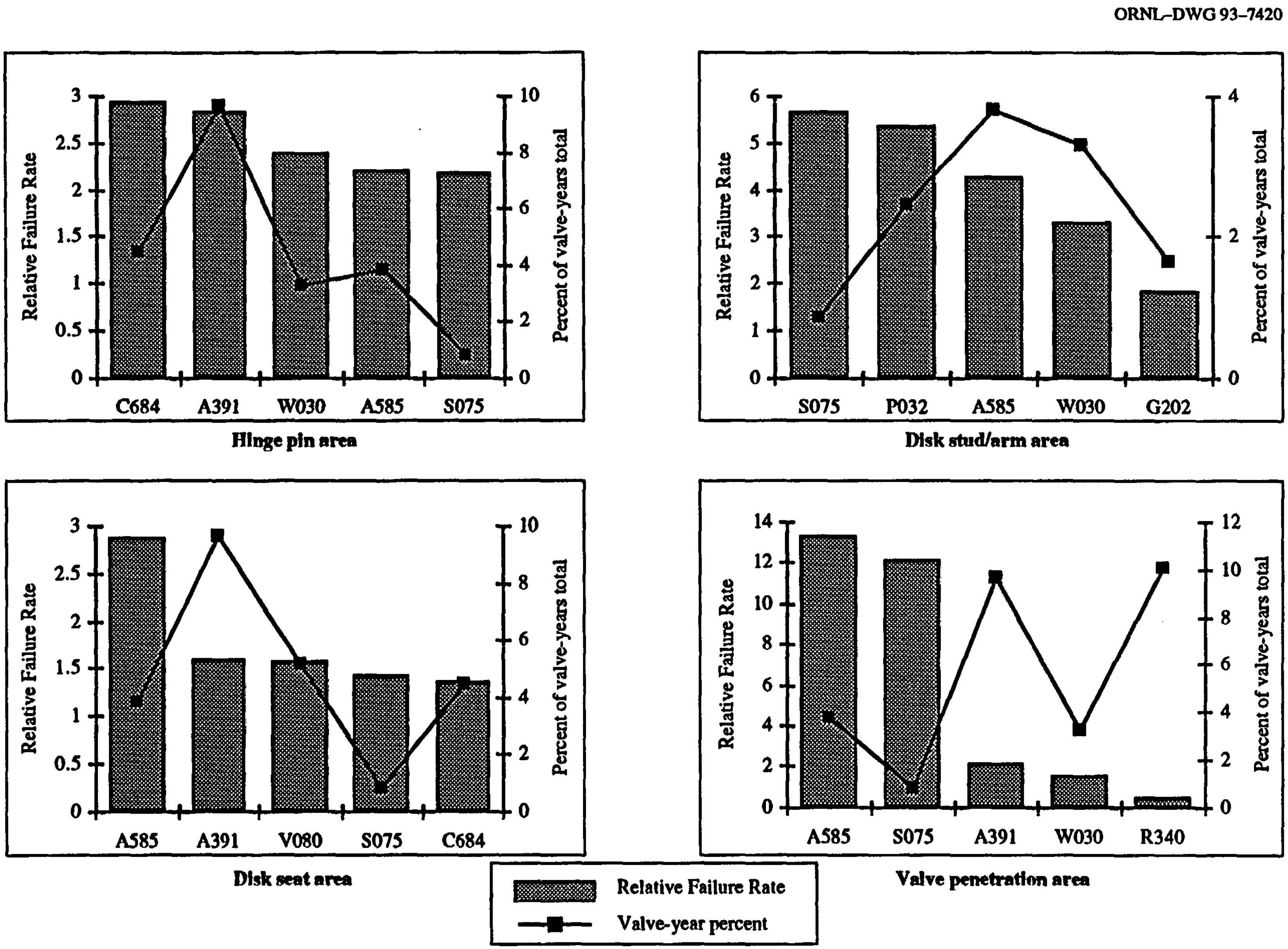


Figure A.8.5 Relative failure rates and percentage of valve population service life for the five manufacturers with the highest failure rate in the four listed failure areas. The charts are sorted by relative failure rate within the particular failure area

ORNL-DWG 93-7421

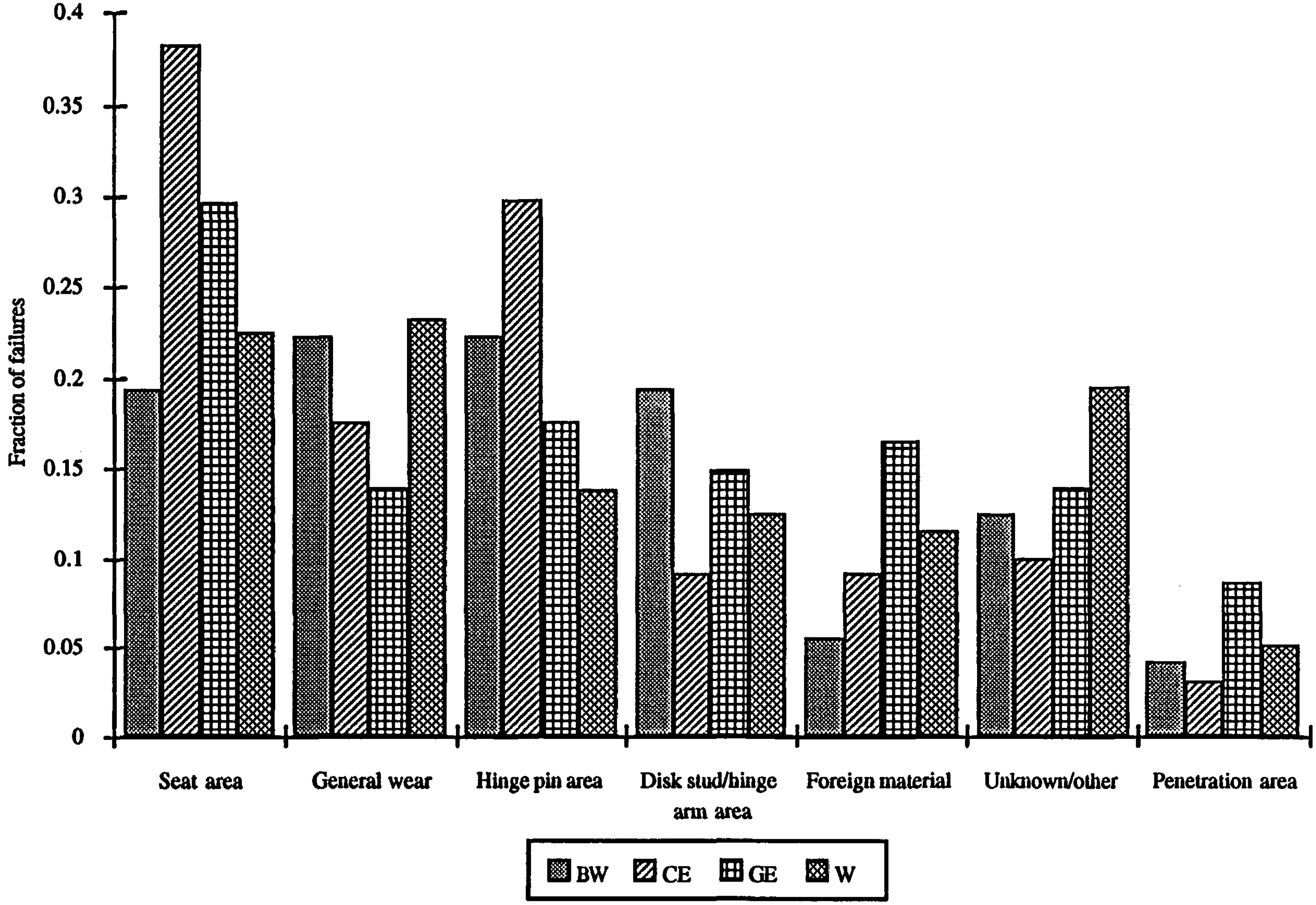


Figure A.8.6 Relative failure rate by failure area and NSSS. The rates shown indicate the relative failure rates by NSSS for the designated failure area. The valve-years weighted average of the values for any failure mode category equals one

ORNL-DWG 93-7422

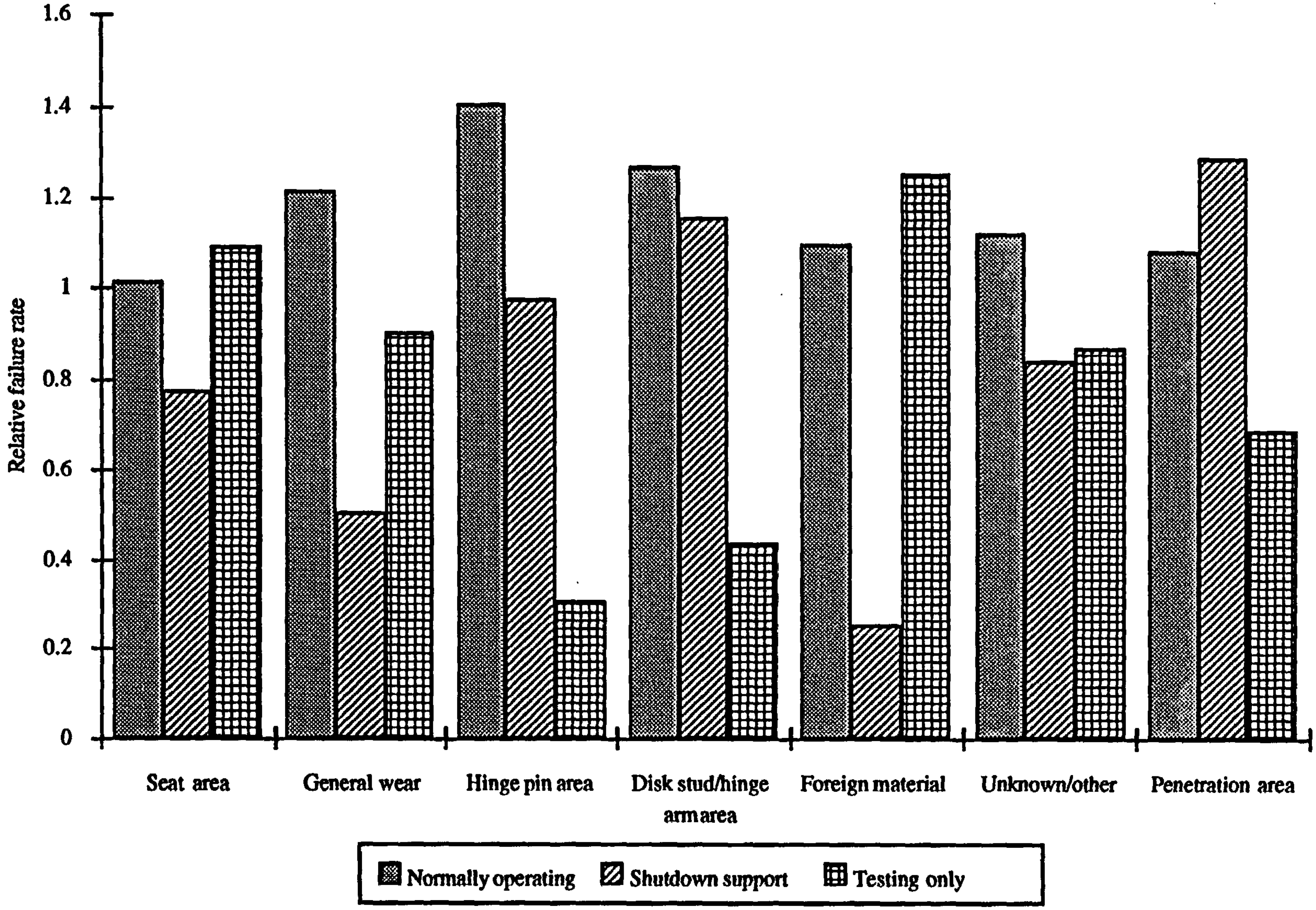


Figure A.8.7 Relative failure rate by failure area and system status. The failure rate values are relative to the overall failure rate within the given failure area category, such that the service-weighted average of the failure rates within that category equals one

ORNL-DWG 93-7423

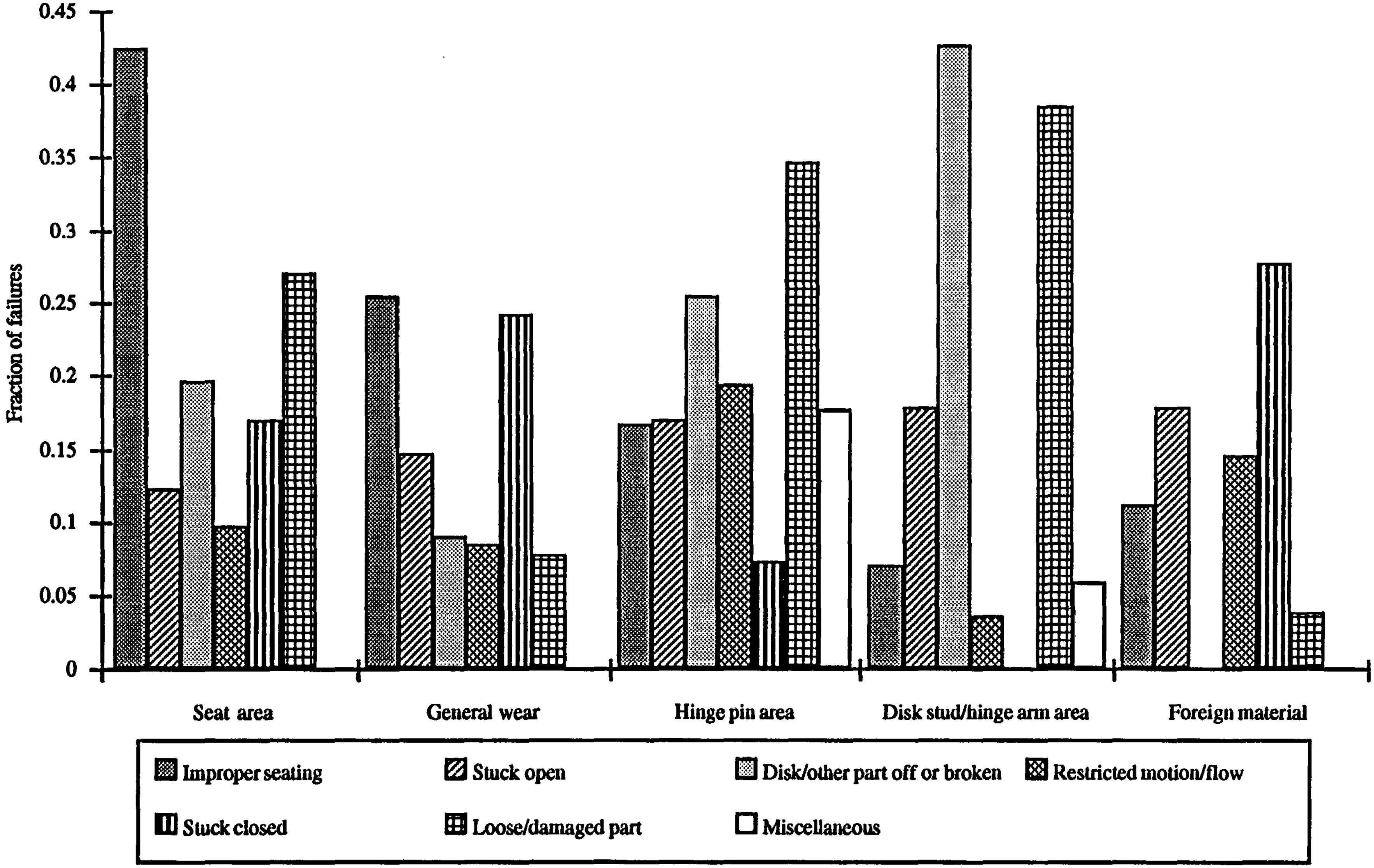


Figure A.8.8 Fraction of failures in which the designated area was affected for selected failure modes and areas

ORNL-DWG 93-7424

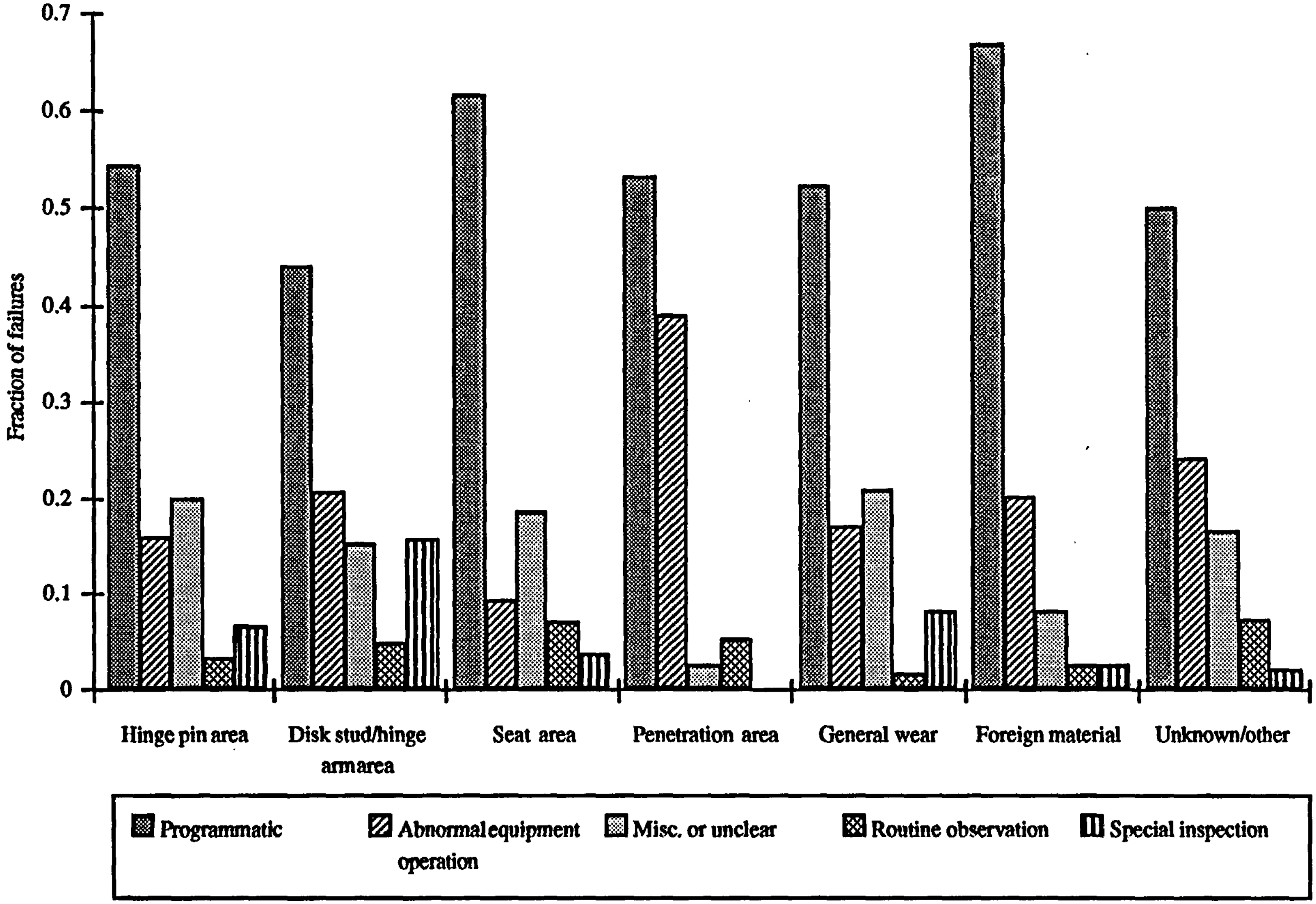


Figure A.8.9 Fraction of failures by general detection method for selected failure areas

ORNL–DWG 93–7425

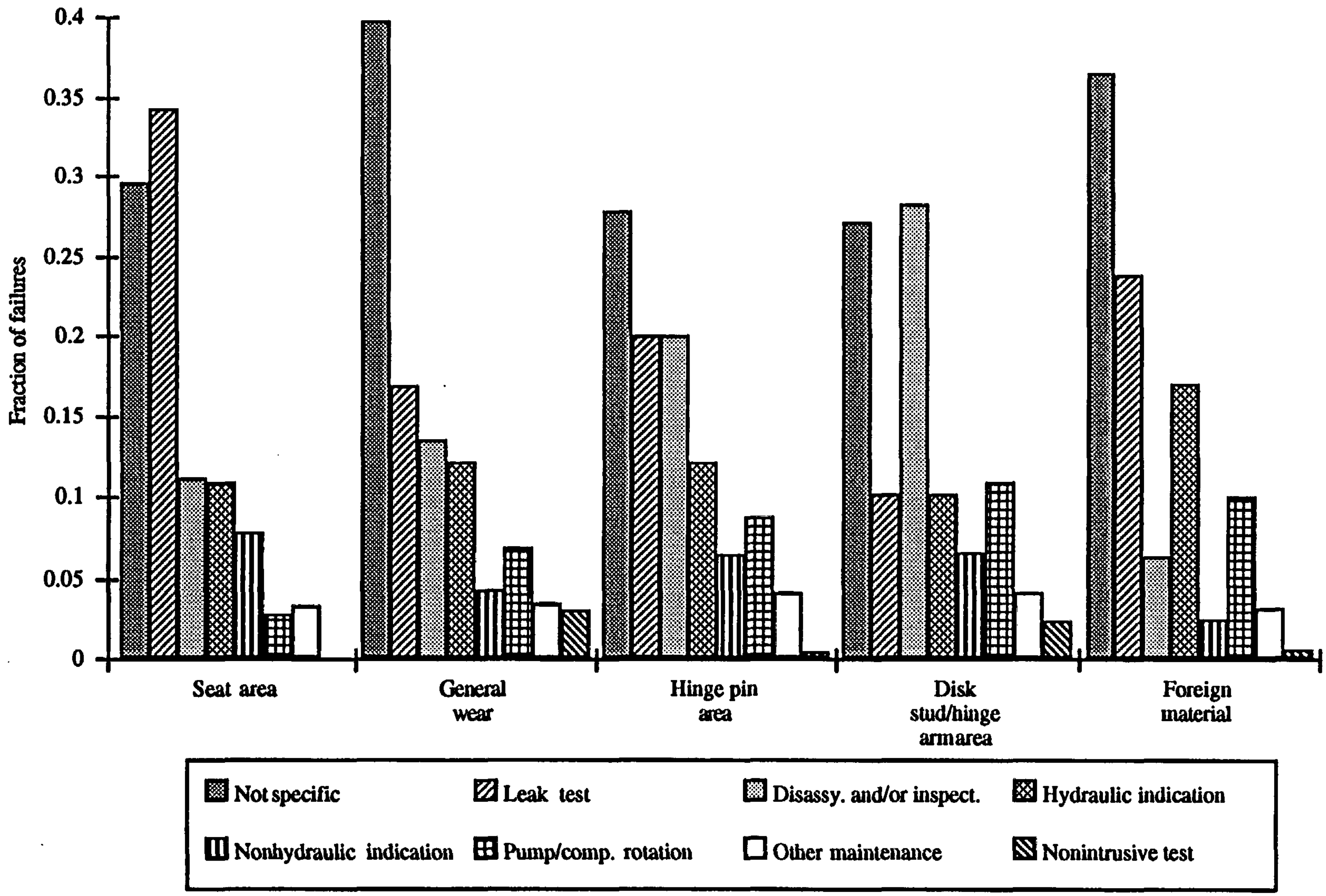


Figure A.8.10 Fraction of failures detected by specific detection methods for selected failure areas

ORNL-DWG 93-7426

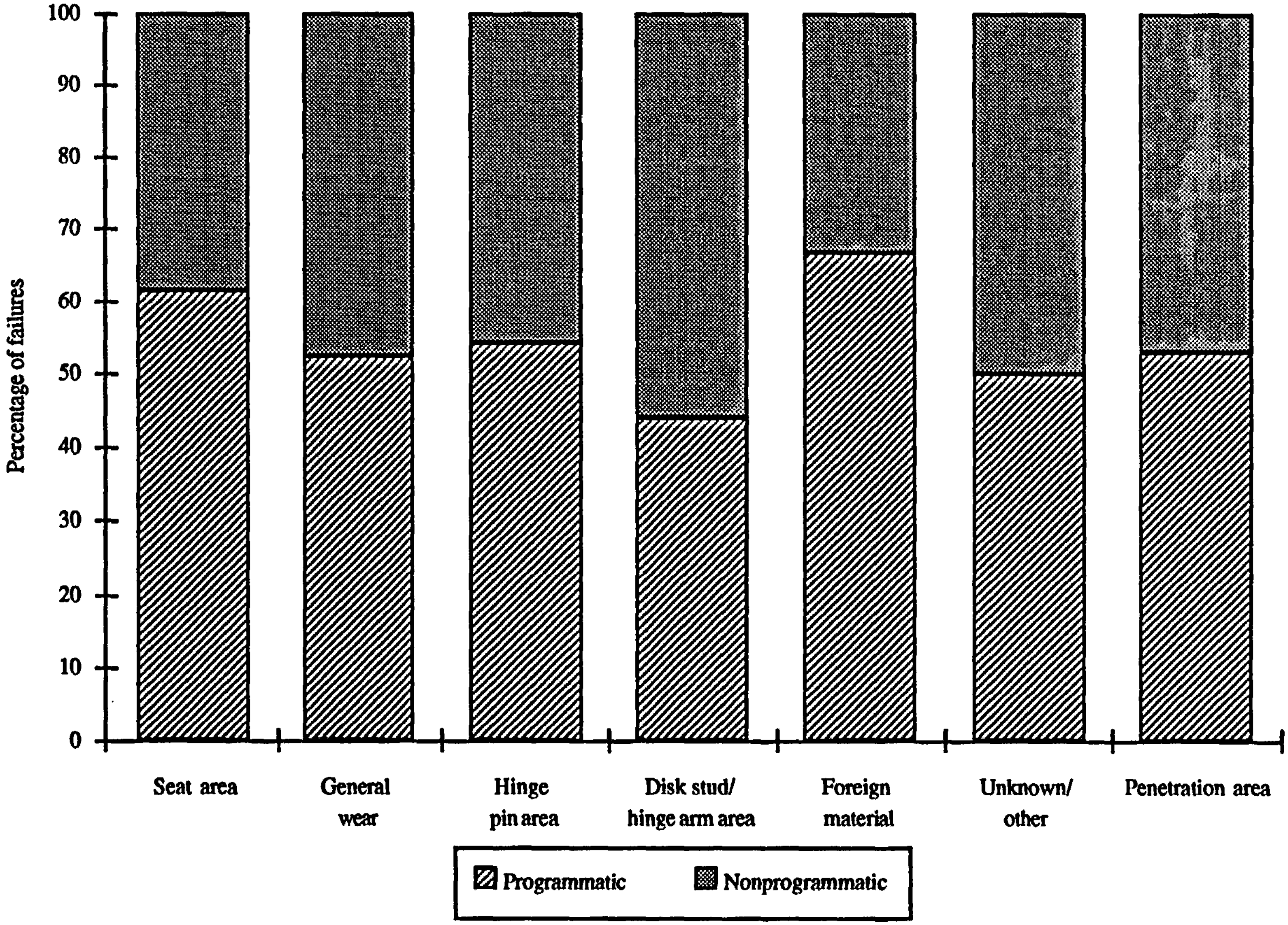


Figure A.8.11 Distribution of failures by discovery process and affected area

ORNL-DWG 93-7427

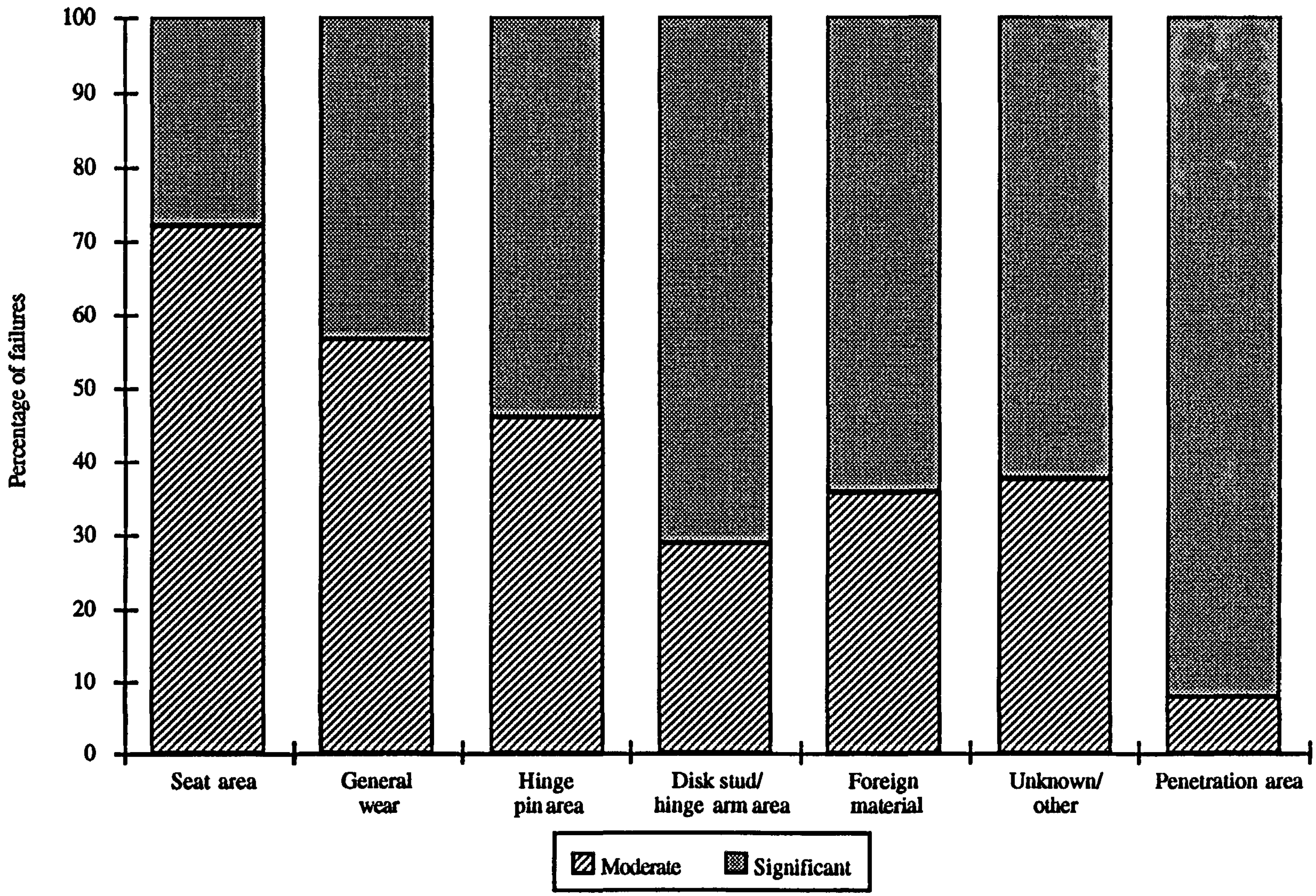


Figure A.8.12 Distribution of failures by failure area and extent of degradation

ORNL-DWG 93-7428

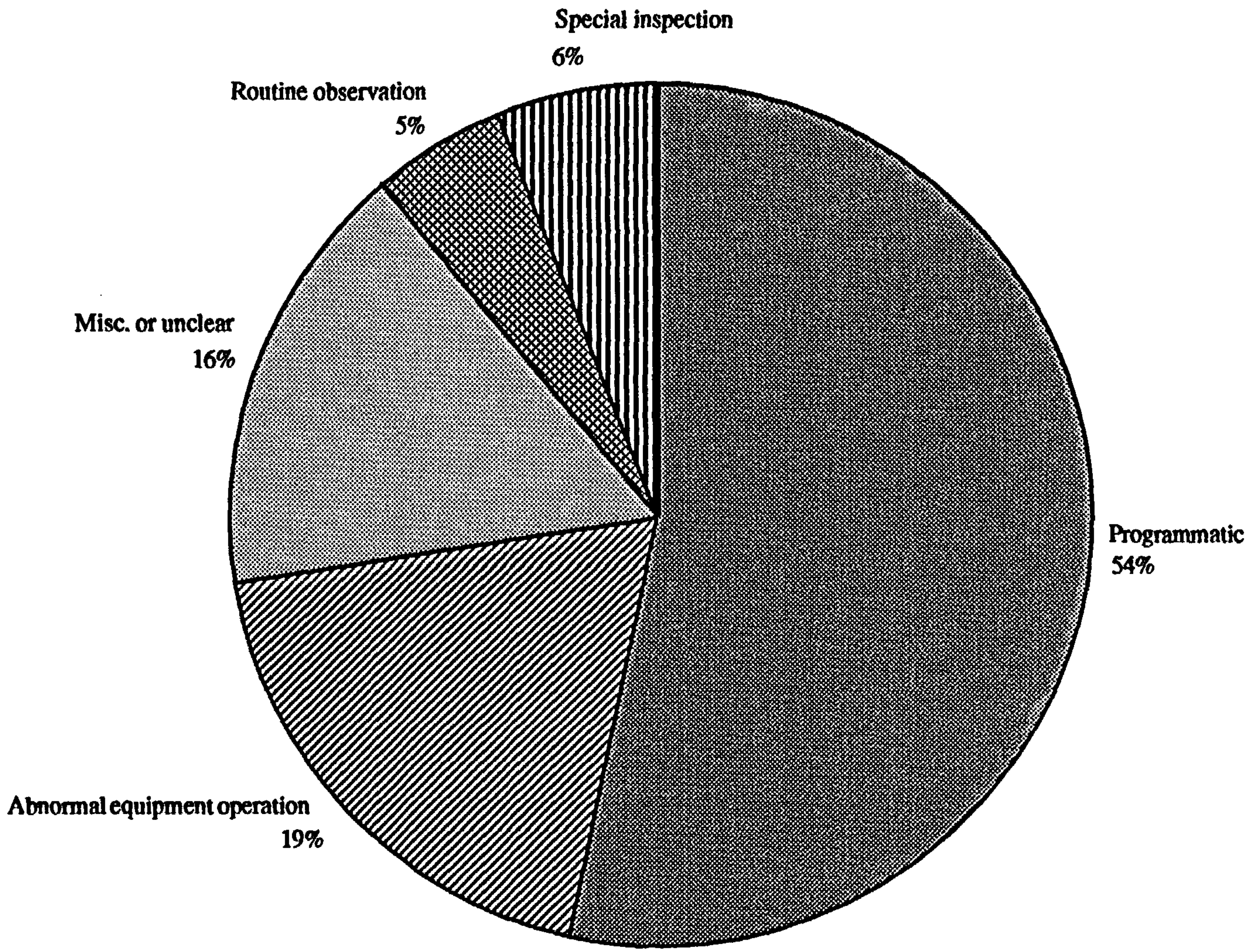


Figure A.9.1 Distribution of failures by general detection method

ORNL–DWG 93–7429

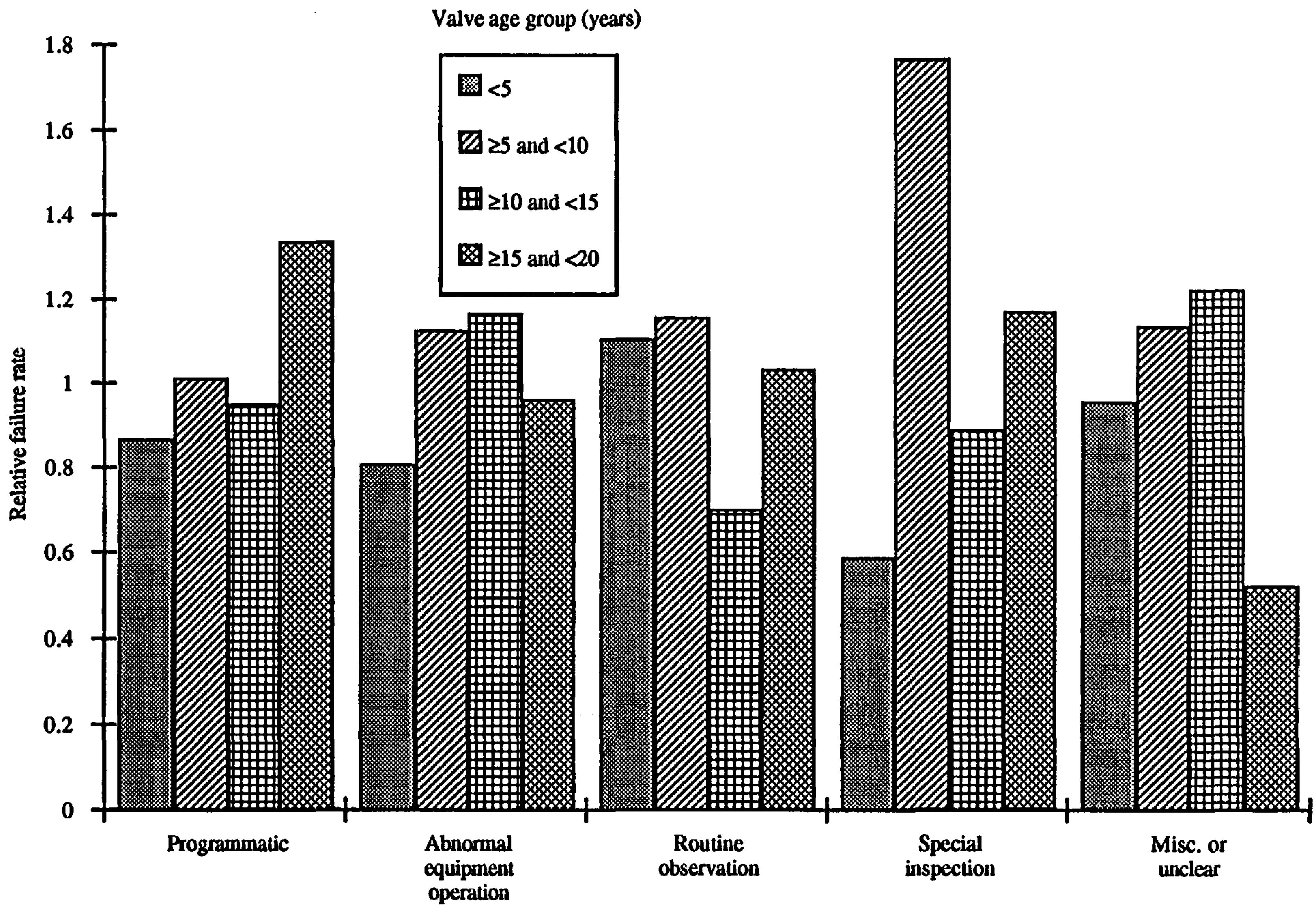


Figure A.9.2 Relative failure rate by general detection method and valve age group. The age group population weighted average within each detection means equals one

ORNL–DWG 93–7430

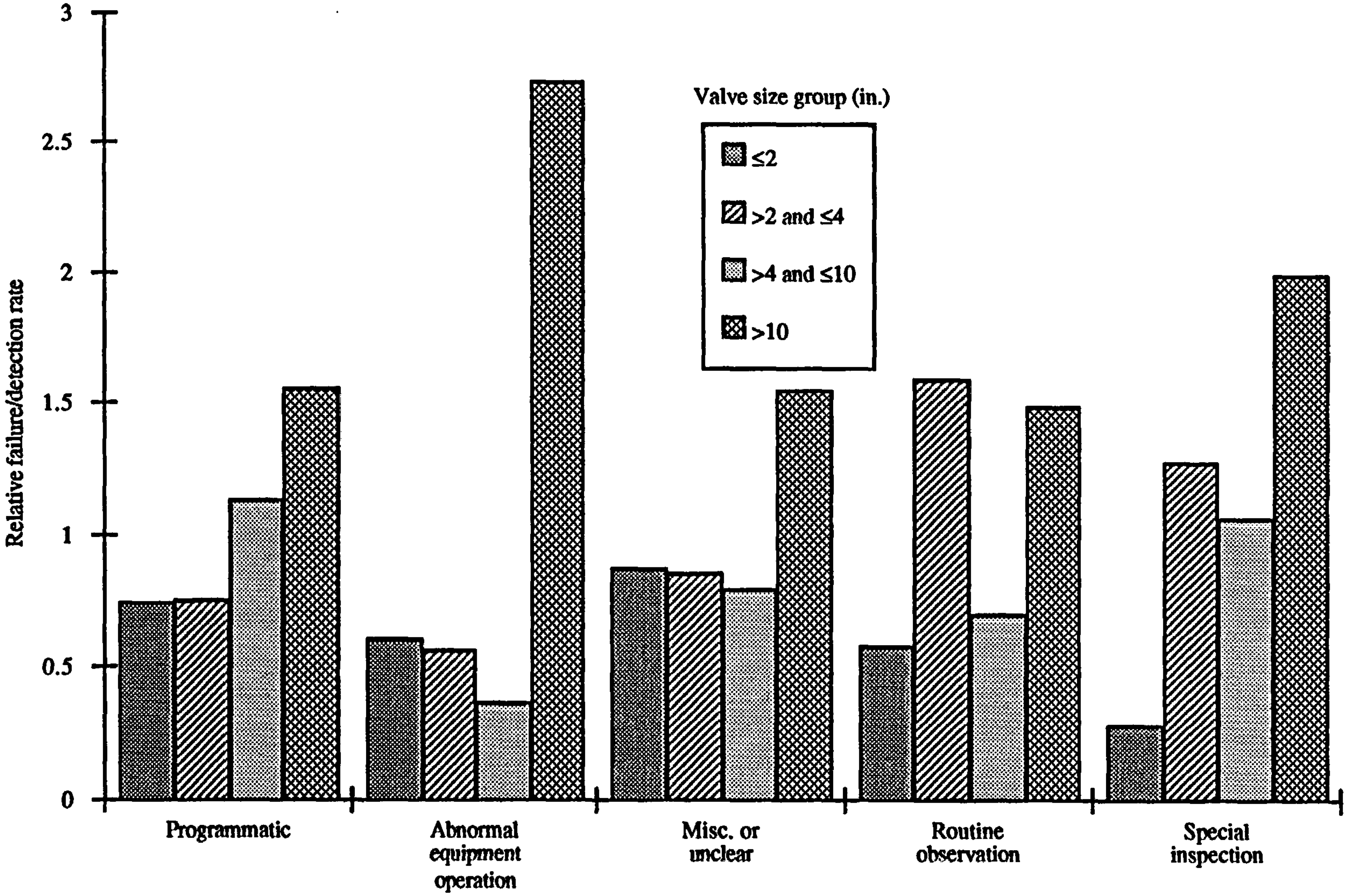


Figure A.9.3 Relative failure rate by general detection method and valve size group. The size group population weighted average within each detection means equals one

ORNL–DWG 93–7431

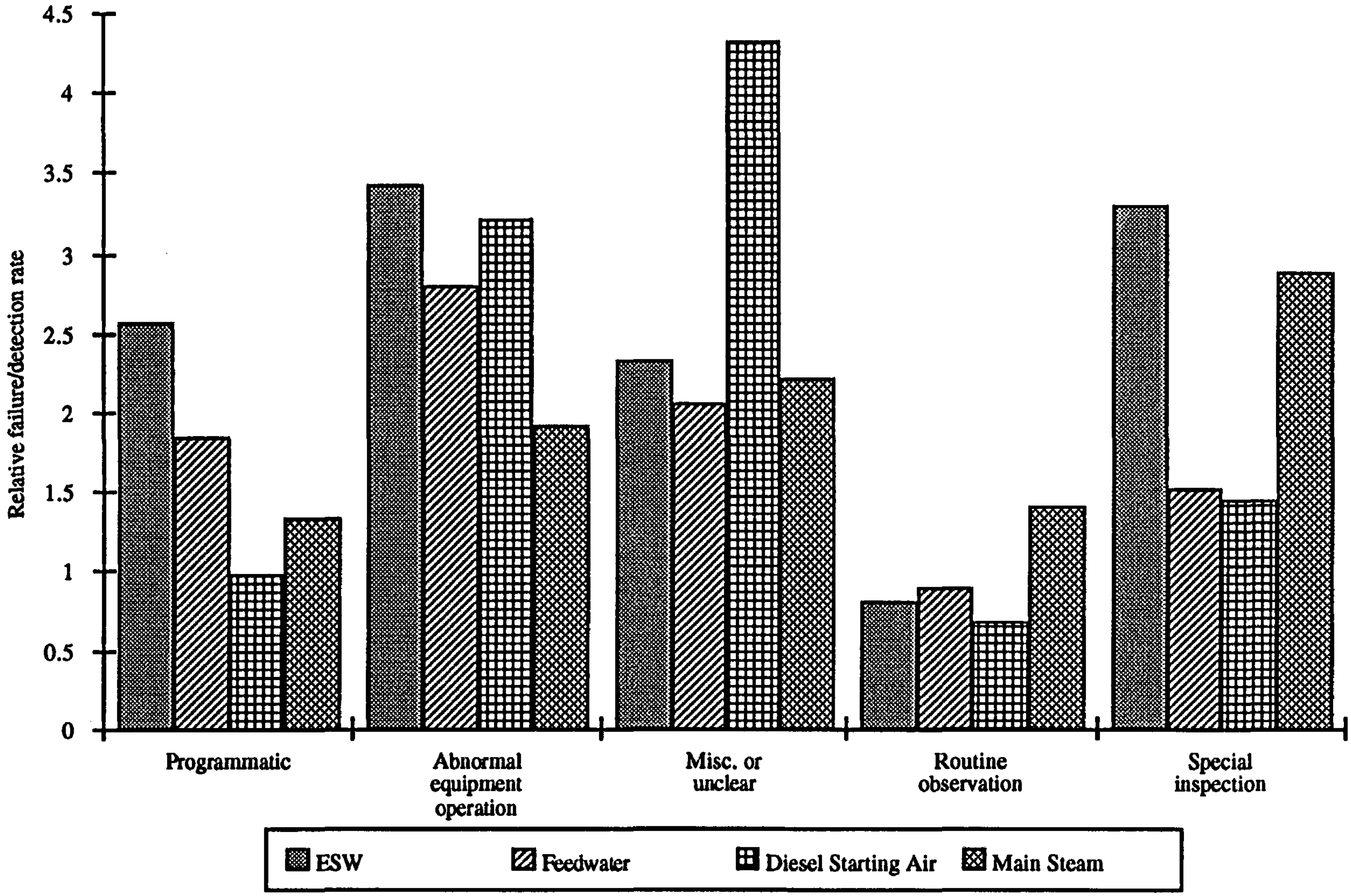


Figure A.9.4 Relative failure rate by general detection method and system for four systems with highest overall failure rate. The rates indicated are based on a normalized failure rate of one for all systems for the designated general detection method. For example, ESW valves experienced programmatically detected failures at just over 2.5 times the overall population

ORNL-DWG 93-7432

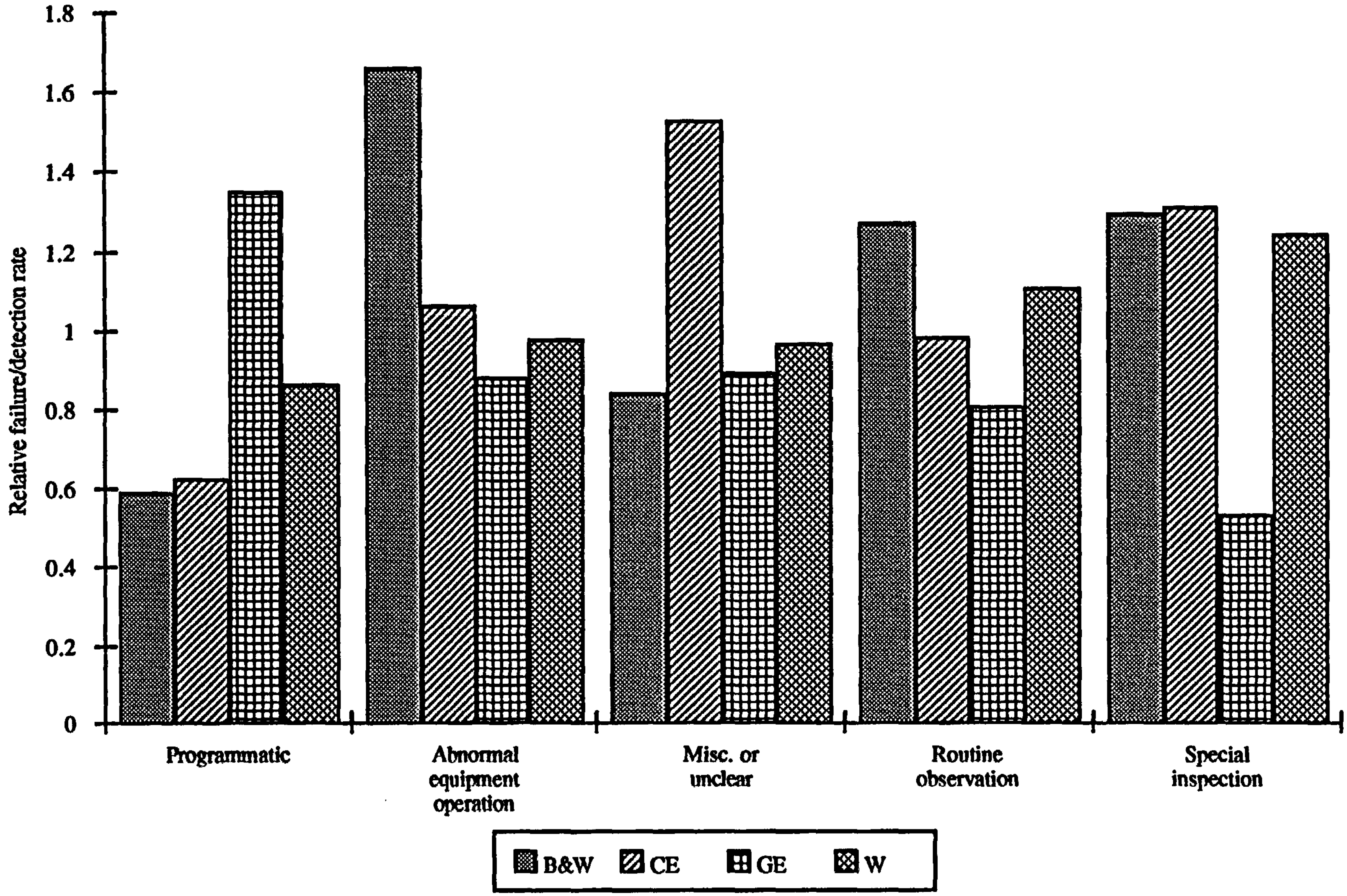


Figure A.9.5 Relative failure rate by general detection method and NSSS. The valve-years weighted average of the values for any general detection category equals one

ORNL-DWG 93-7433

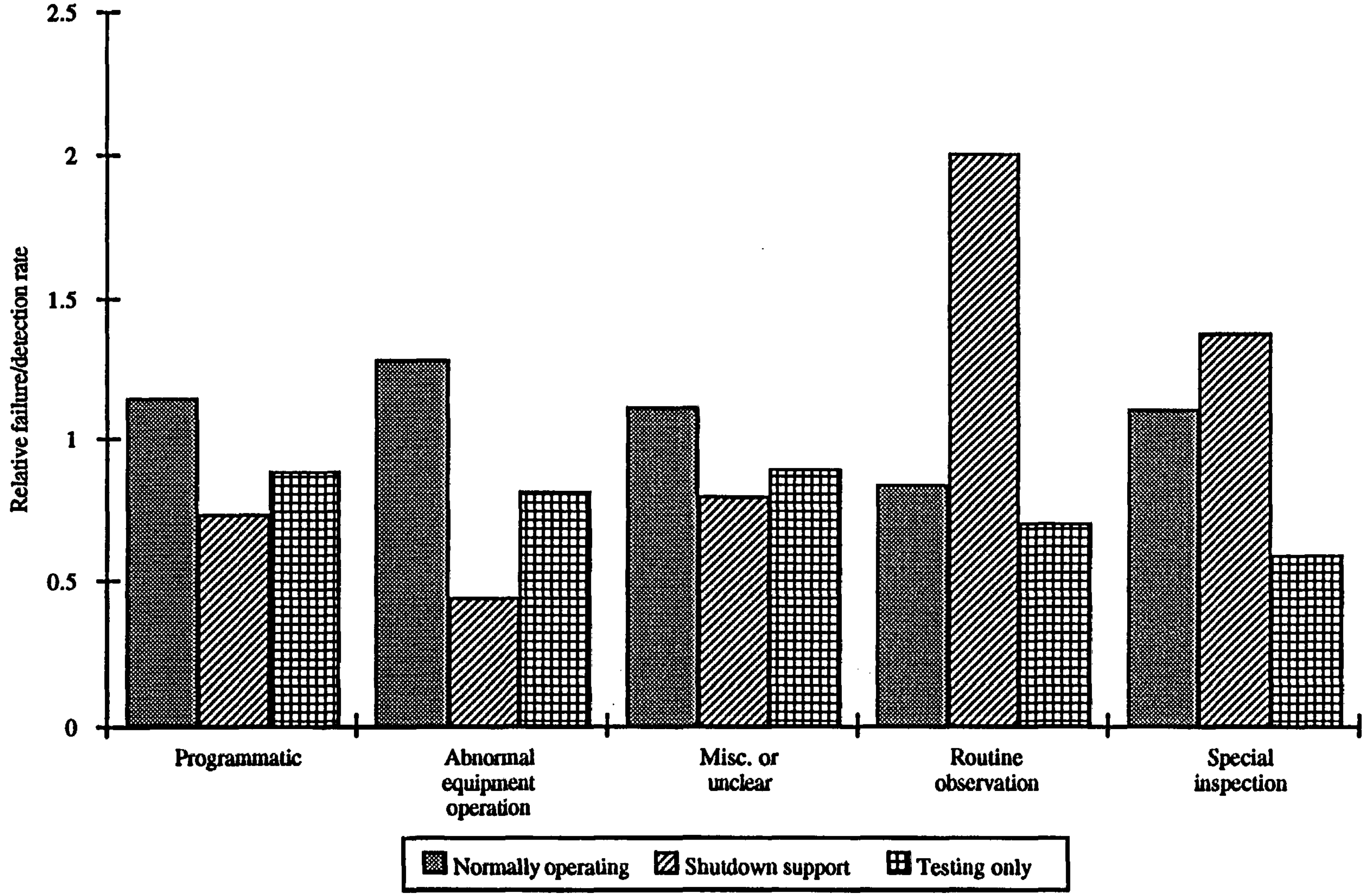


Figure A.9.6 **Relative failure/detection rate of general detection methods by system usage. The rates shown indicate how many failures were detected by the desginated detection method within the specified system usage category, in relation to how well the method was used overall. The valve-years weighted average of the values for any given detection method equals one**

ORNL-DWG 93-7434

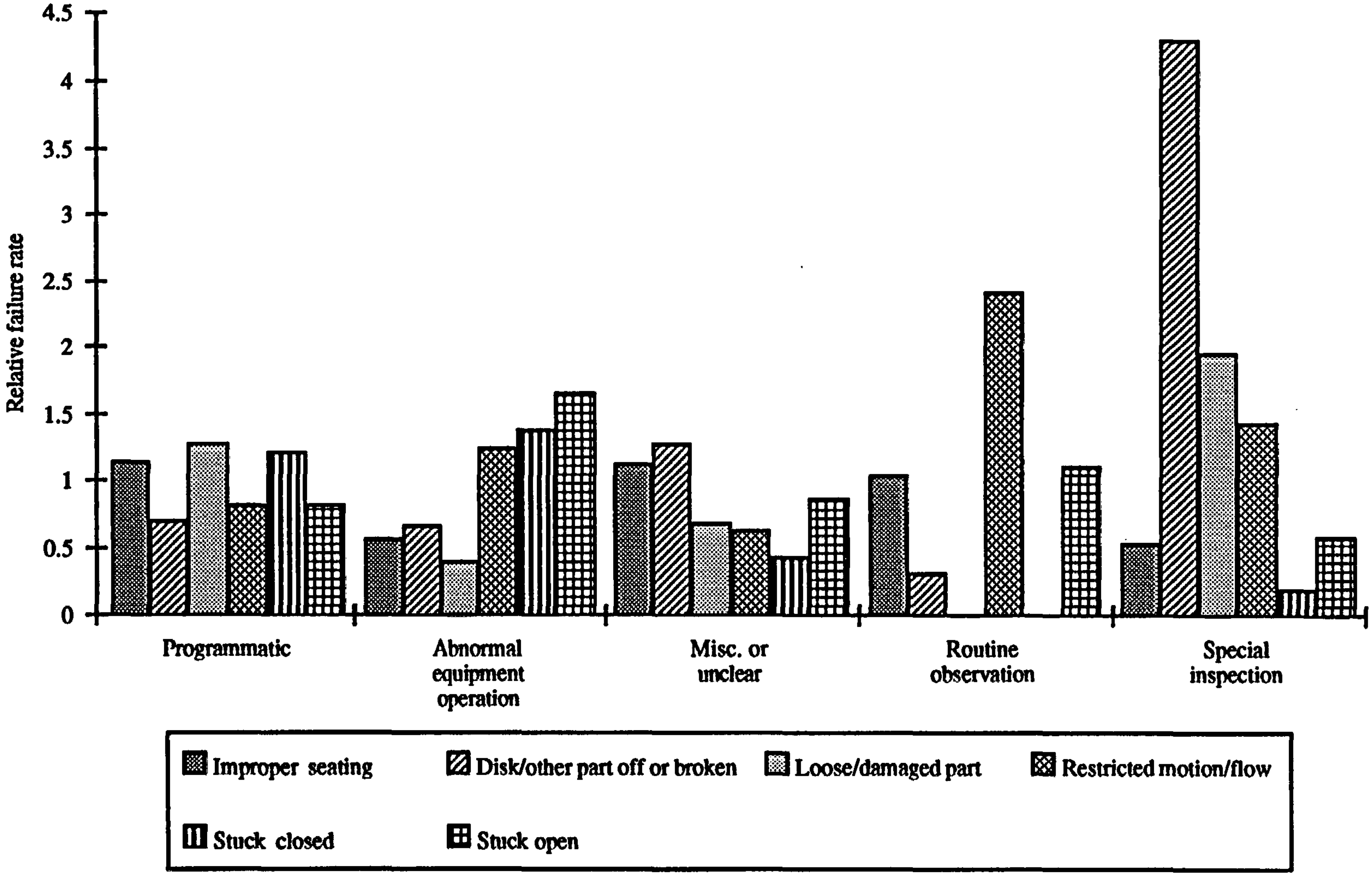


Figure A.9.7 Relative historical success rate of selected general detection methods in discovering selected failure modes. The values shown represent how well a particular detection method has been in finding the designated failure mode in comparison to all detection methods. The weighted (by number of failures) average of all failure modes for each general detection method equals one

ORNL-DWG 93-7435

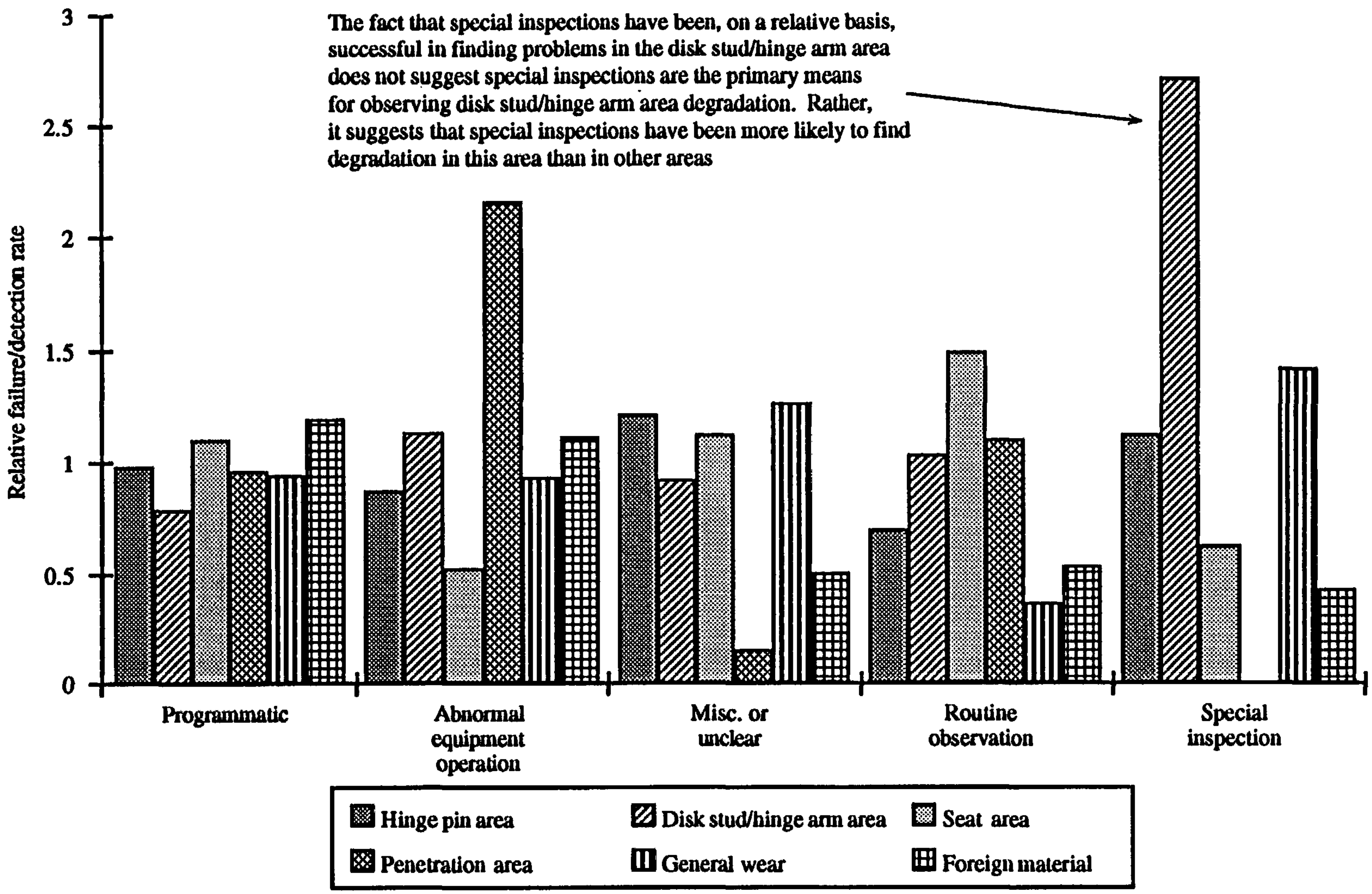


Figure A.9.8 Relative historical success rate of general detection methods in discovering selected failure areas. The values shown represent how well a particular detection method has been in finding the designated failure area in comparison to all detection methods. The weighted (by number of failures) average of all failure areas for each general detection method equals one

ORNL-DWG 93-7436

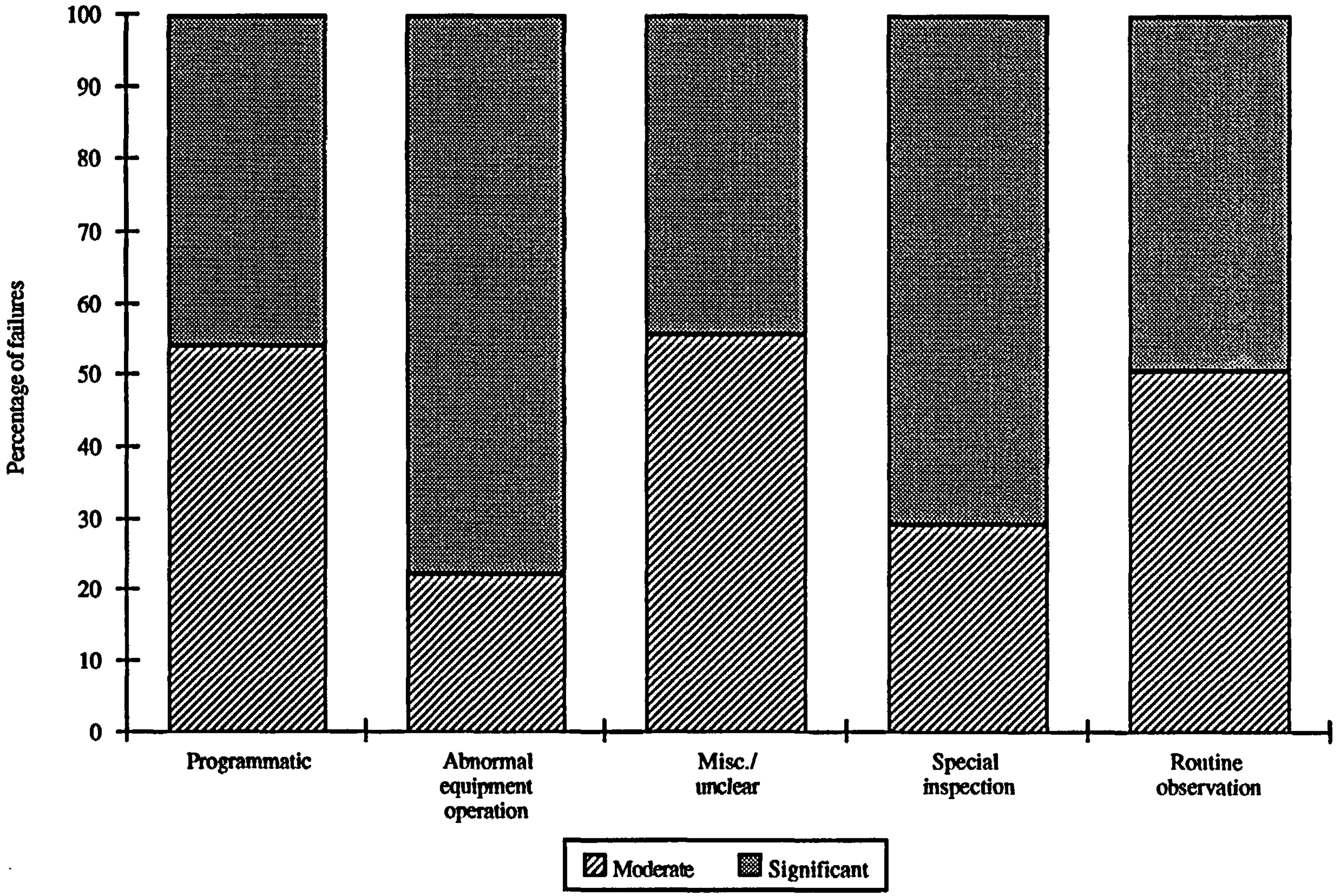


Figure A.9.9 Distribution of failures by general detection method and extent of degradation

ORNL–DWG 93–7437

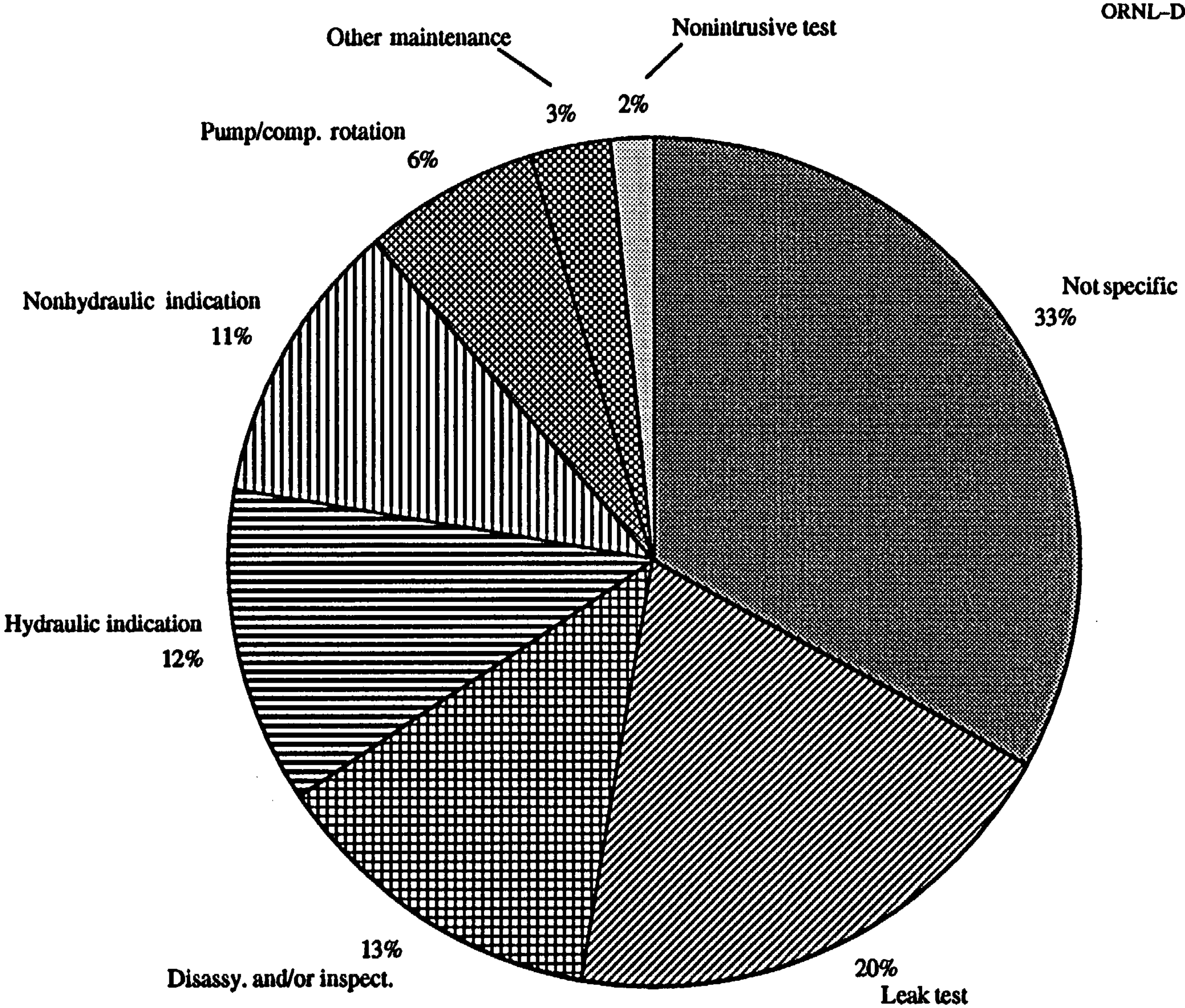


Figure A.10.1 Distribution of failures by specific detection method

ORNL-DWG 93-7438

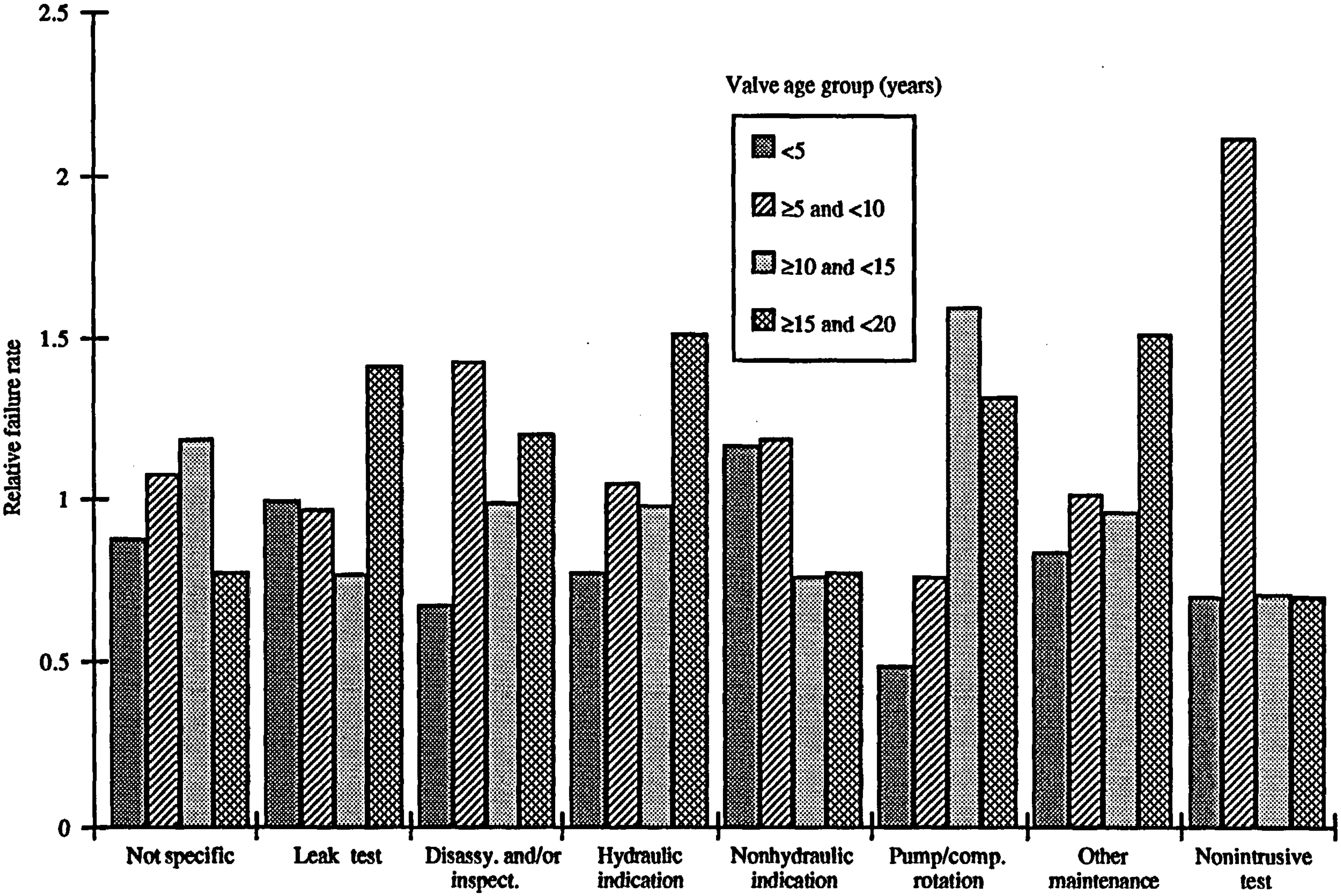


Figure A.10.2 Relative failure rate by valve age group and specific detection method. The age group population weighted average within each detection means equals one

ORNL-DWG 93-7439

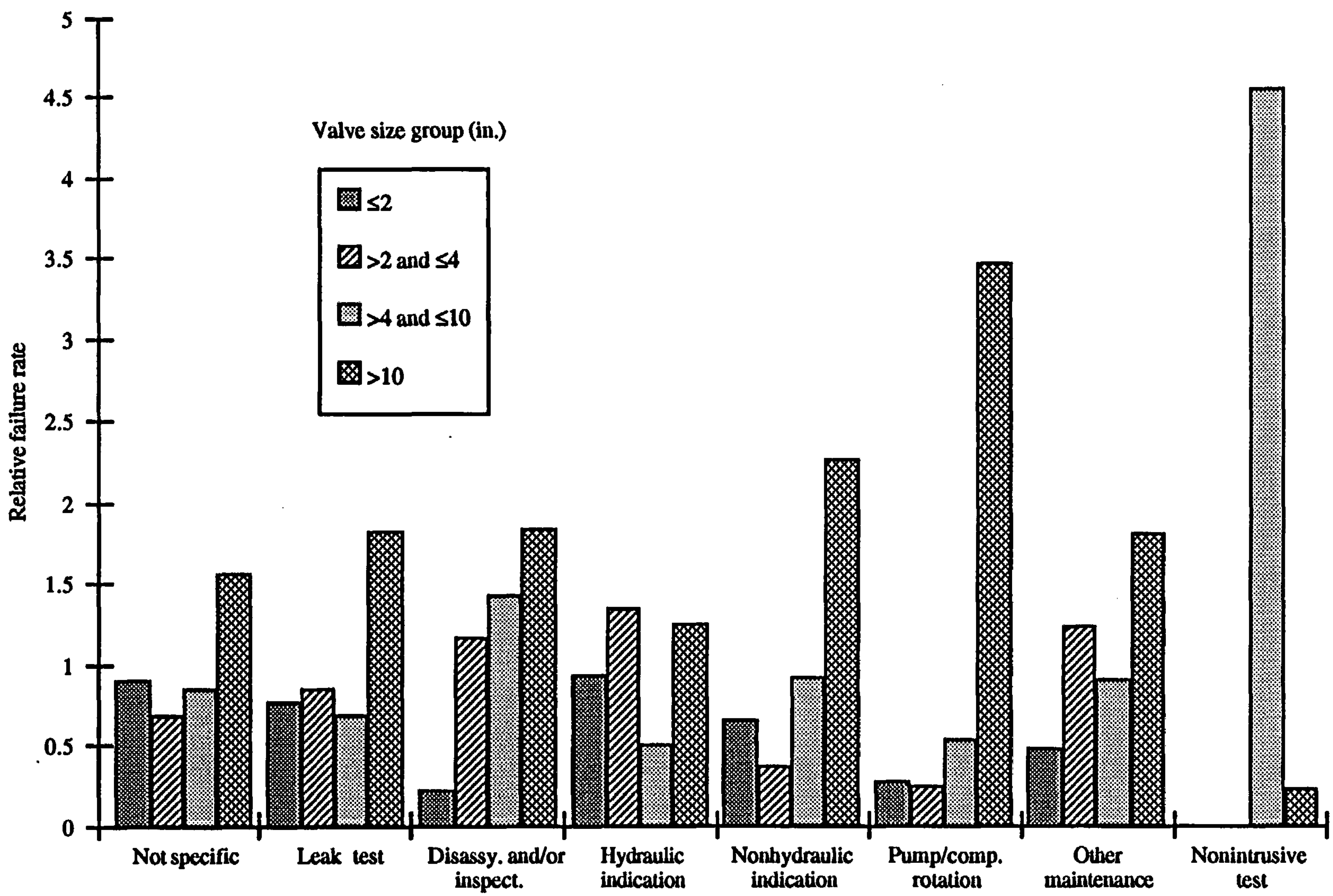


Figure A.10.3 Relative failure rate by specific detection method and valve size group. The size group population weighted average within each detection means equals one

ORNL-DWG 93-7440

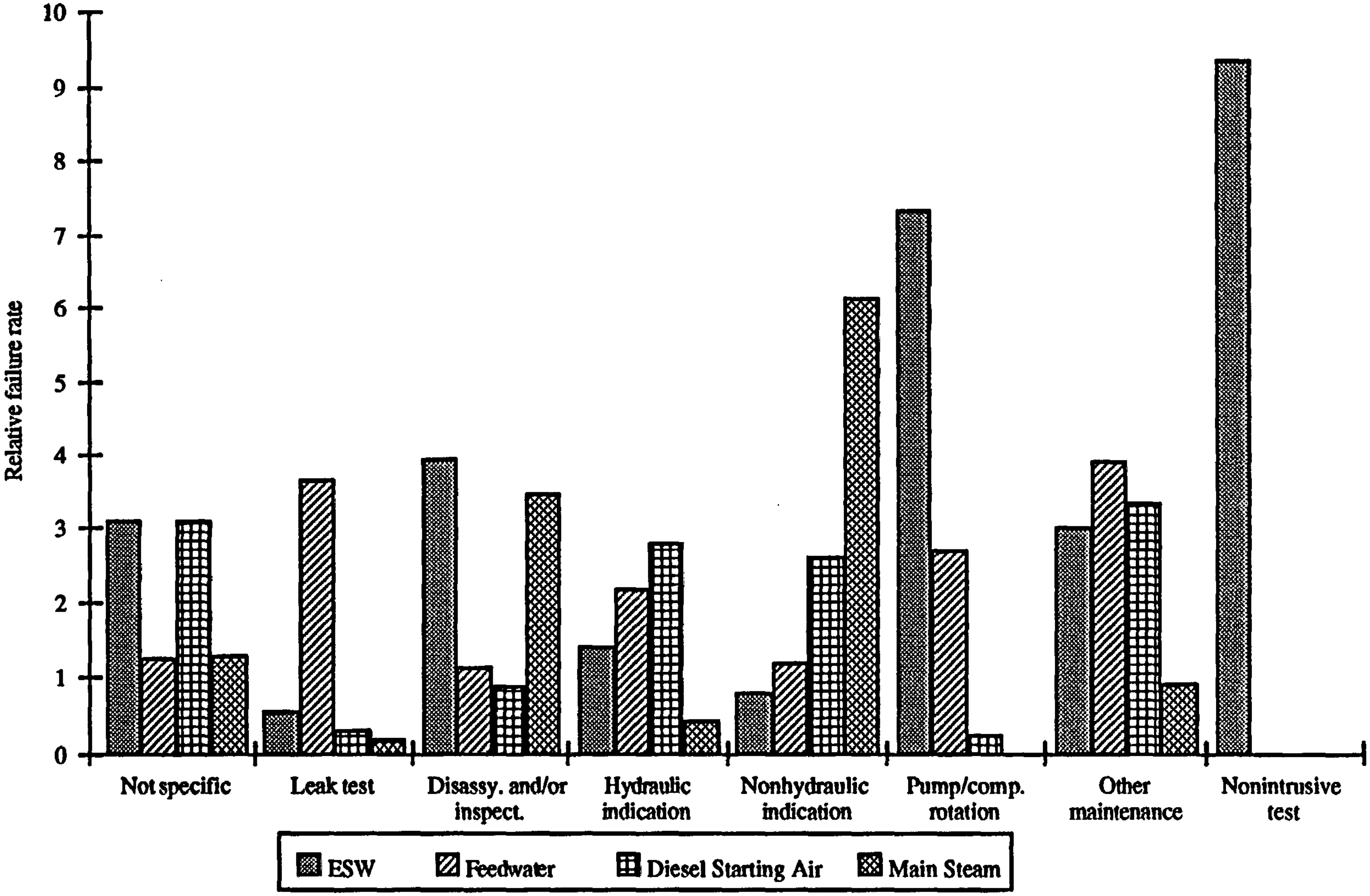


Figure A.10.4 Relative failure rate by specific detection method and system for four systems with highest overall failure rate. The rates indicated are based on a normalized failure rate of one for all systems for the designated specific detection method. For example, non-intrusive means were used to detect ESW failures at over nine times the rate for all systems; note that no failures of feedwater, diesel starting air, or main steam valves were detected non-intrusively

ORNL-DWG 93-7441

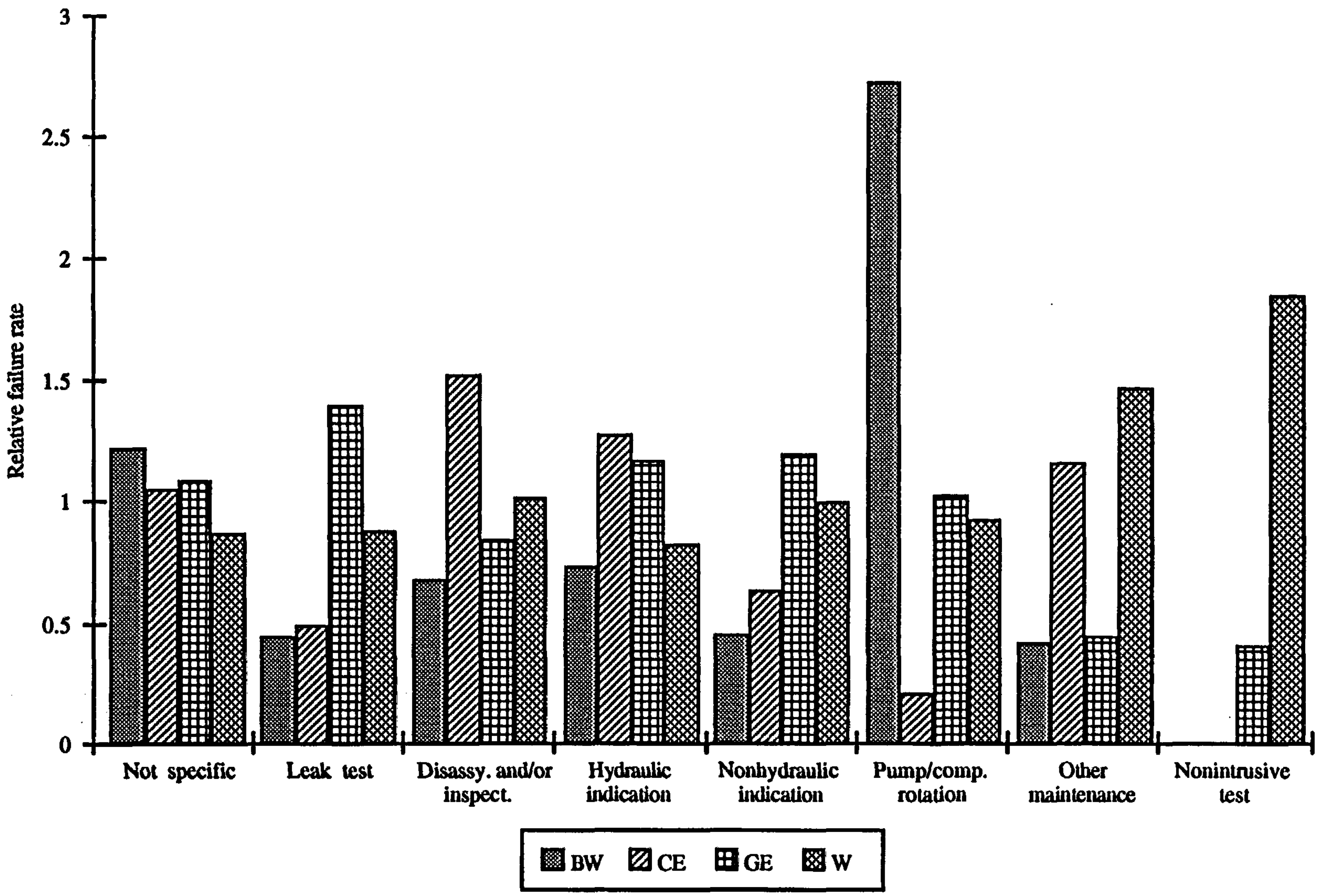


Figure A.10.5 Relative failure rate by specific detection method and NSSS. The valve-years weighted average of the values for any specific detection category equals one

ORNL-DWG 93-7442

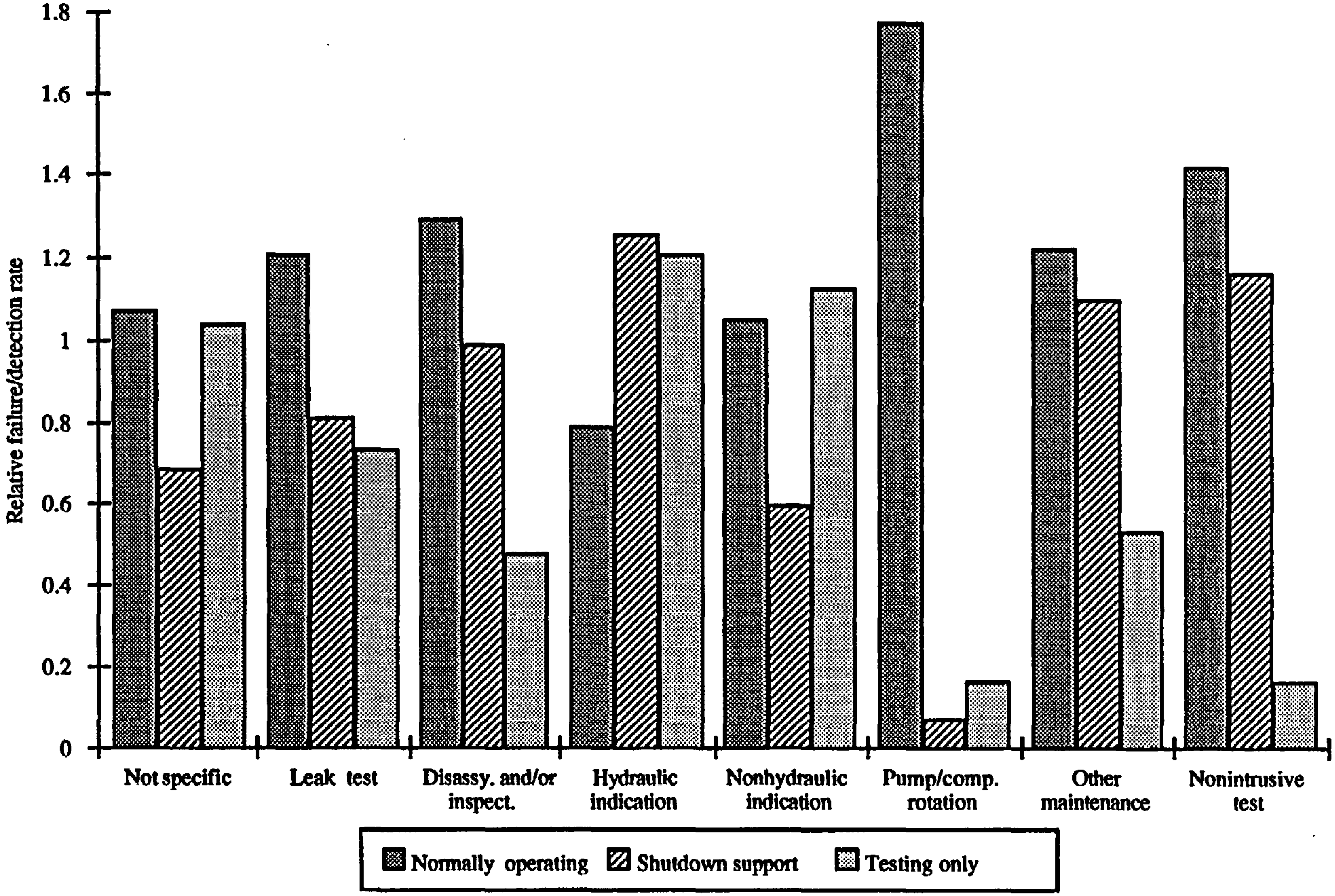


Figure A.10.6 Relative failure/detection rate of specific detection methods by system usage. The rates shown indicate how many failures were detected by the designated detection method within the specified system usage category, in relation to how well the method was used overall. The valve-years weighted average of the values for any given detection method equals one

ORNL-DWG 93-7443

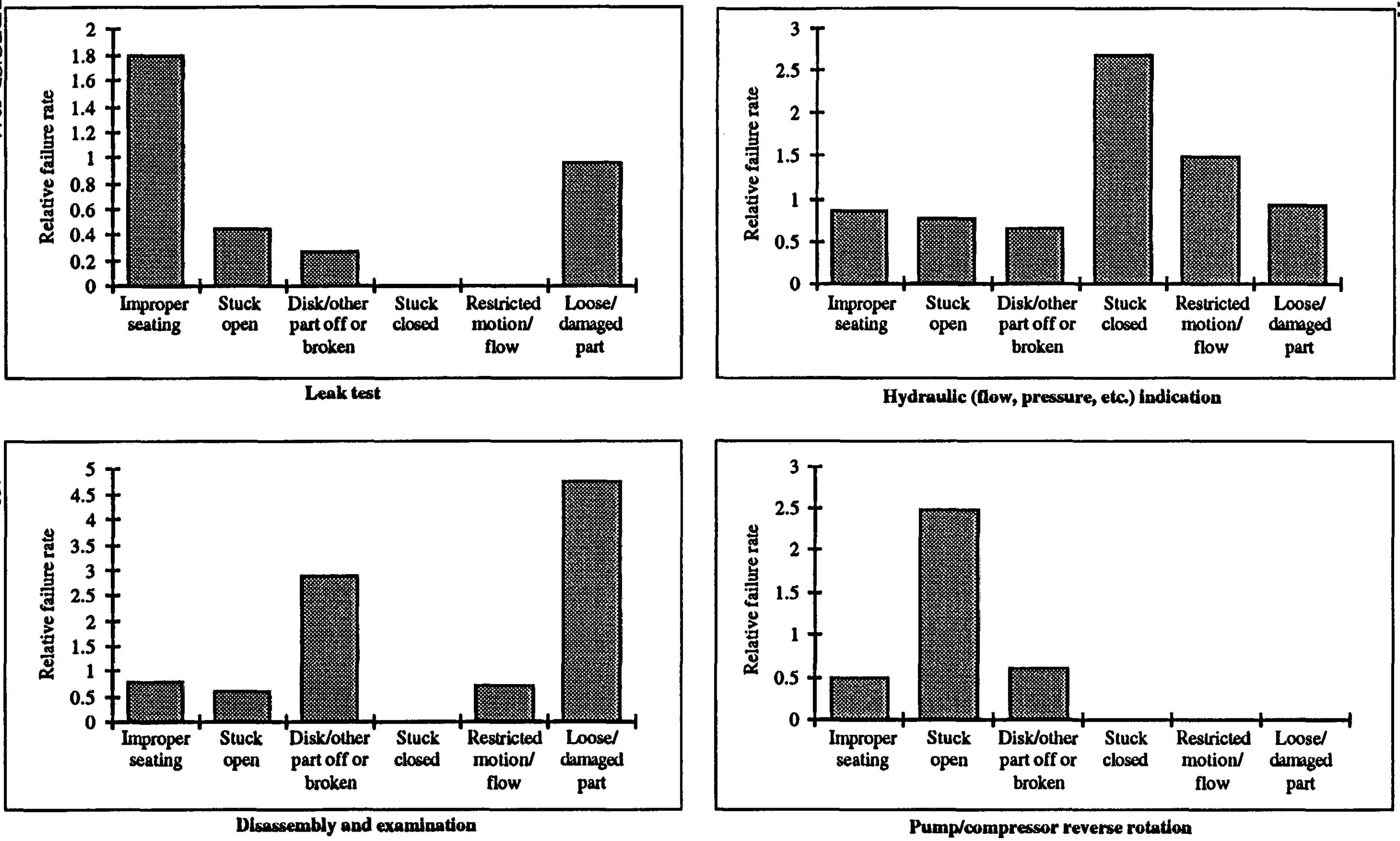


Figure A.10.7 Relative failure rates for selected failure modes and specific detection methods. The values shown reflect the fraction of failures for the particular detection method in which the failure mode was detected, relative to the fraction of failures the specific detection means found overall. Not surprisingly, leak testing was relatively good at indicating improper seating, while disassembly and examination was more effective at finding broken, loose, or impact damaged parts

ORNL-DWG 93-7444

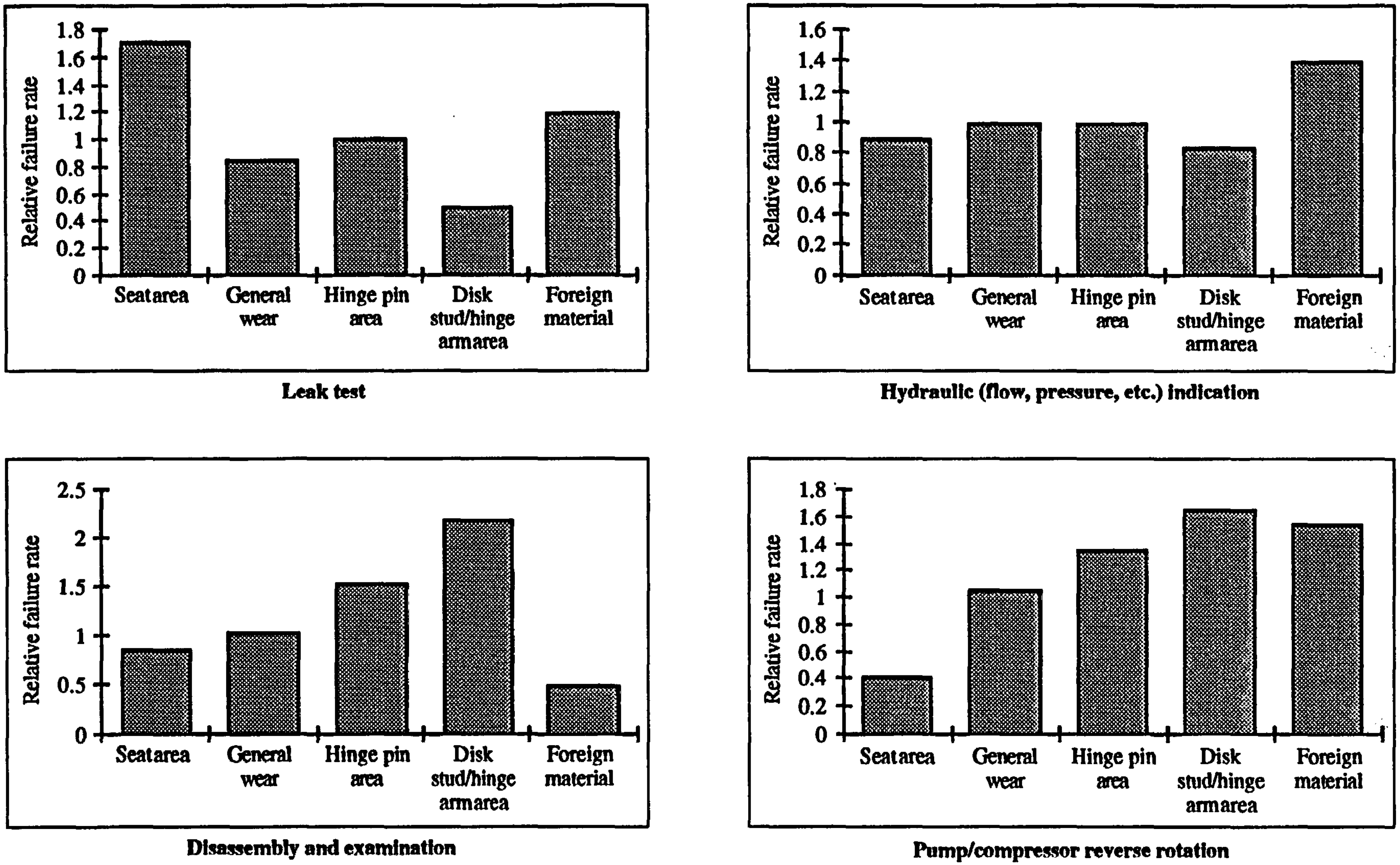


Figure A.10.8 Relative failure rates for selected failure areas and specific detection methods. The values shown reflect the fraction of failures the particular detection method found in the specified areas, relative to the fraction of failures the specific detection means found overall. Not surprisingly, leak testing was relatively good at indicating seat area degradation, while disassembly and examination were more effective at finding hinge pin and disk stud/hinge arm area wear

ORNL-DWG 93-7445

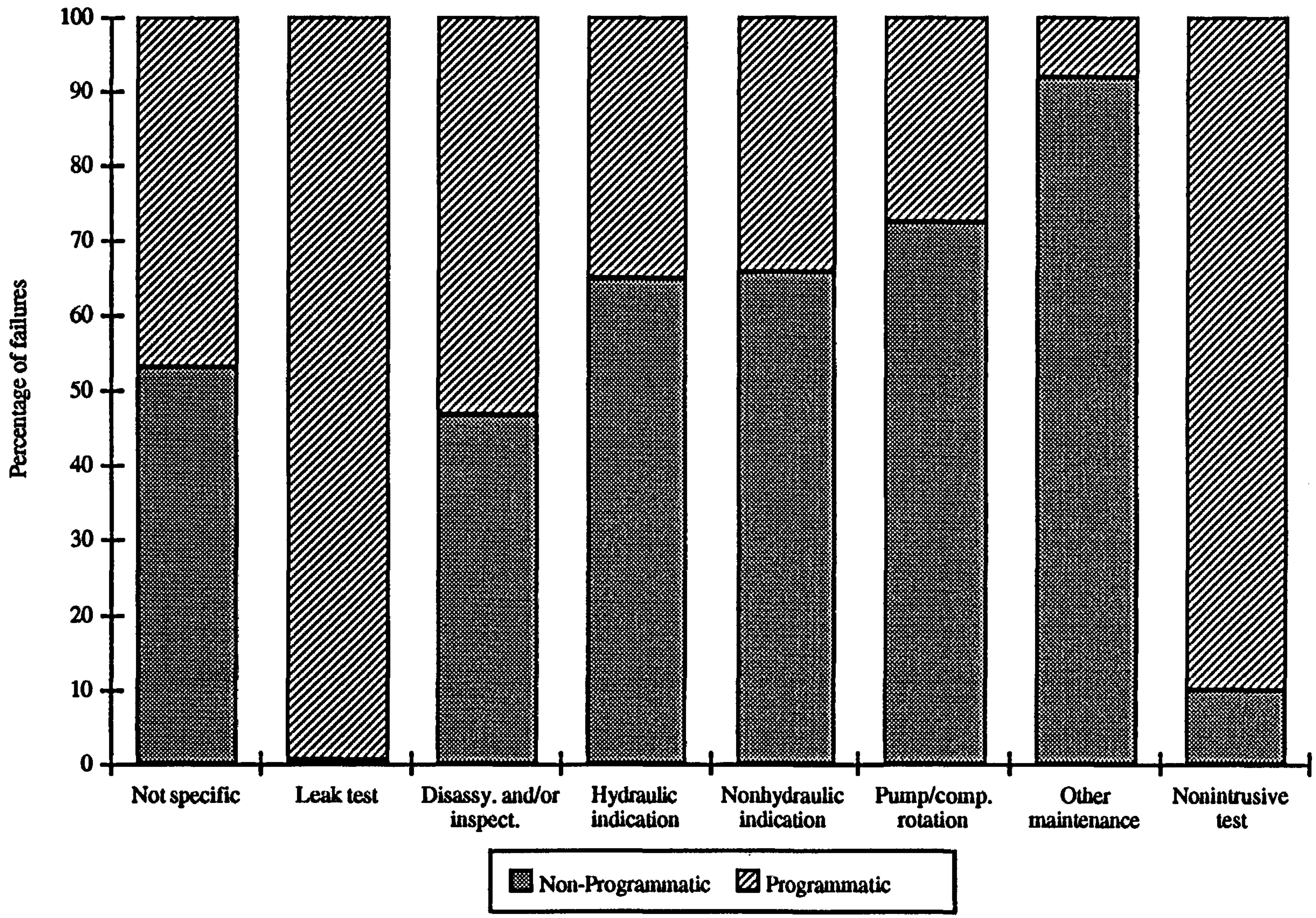


Figure A.10.9 Distribution of failures by specific detection method and general discovery process

ORNL-DWG 93-7446

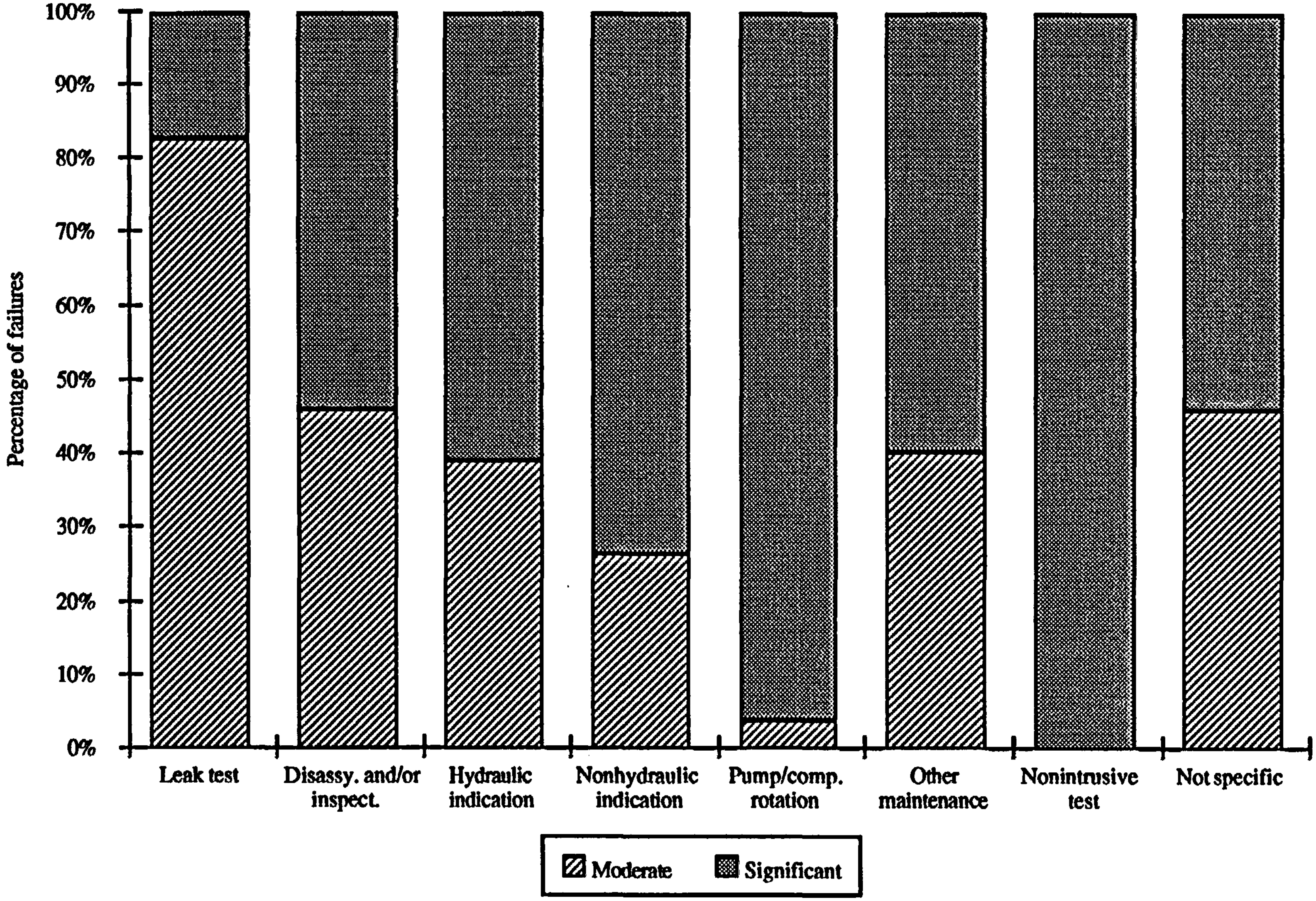


Figure A.10.10 Distribution of failures by specific detection method and extent of degradation

ORNL–DWG 93–7447

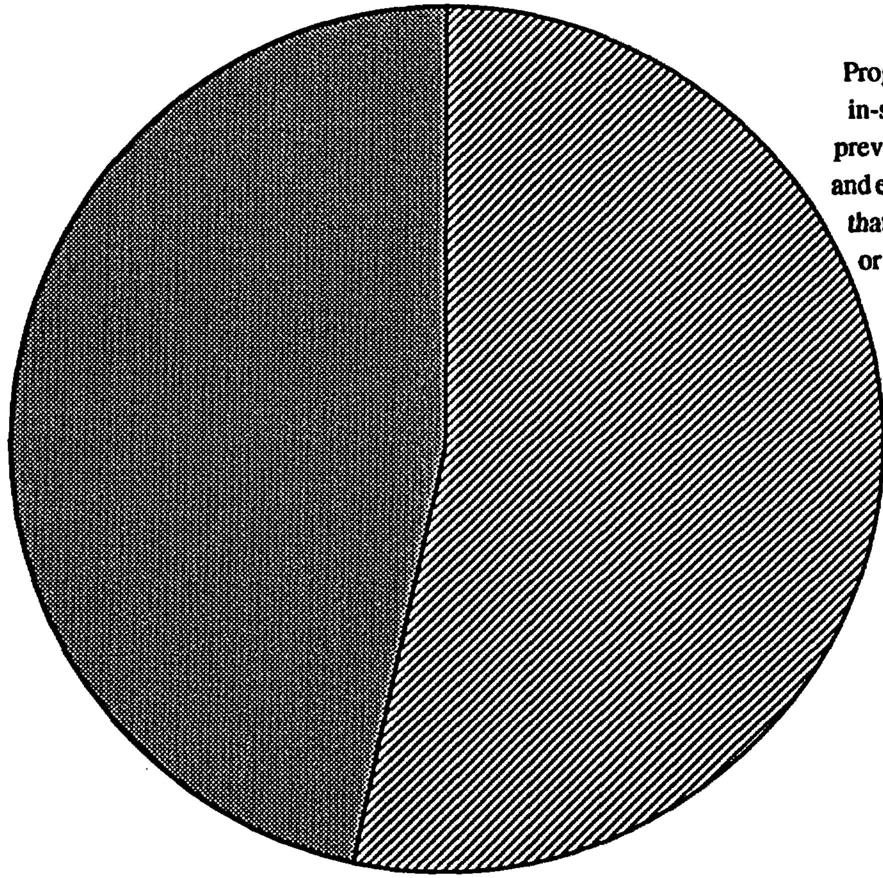


Figure A.11.1 Distribution of failures by discovery process

ORNL-DWG 93-7448

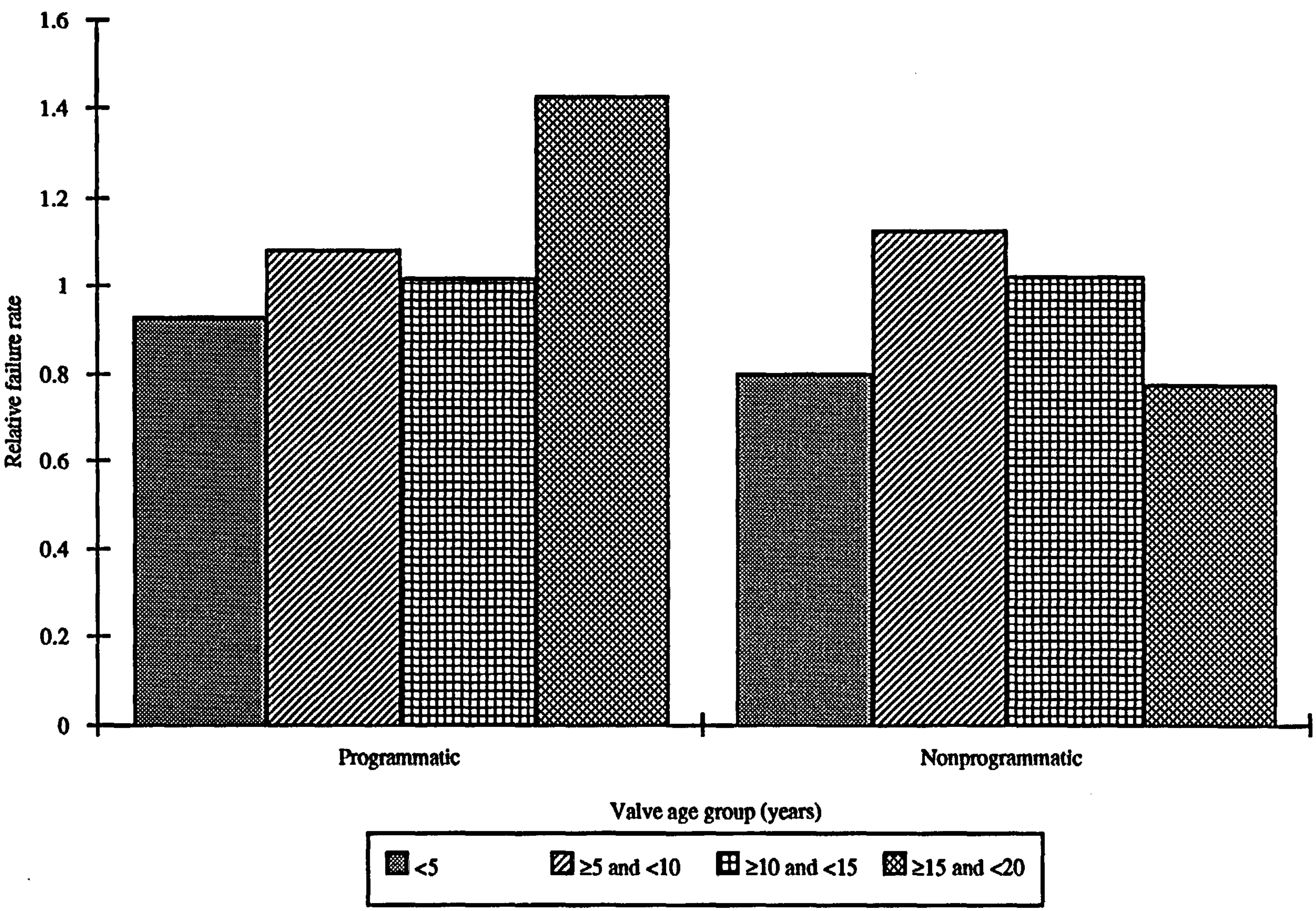


Figure A.11.2 Relative failure rate by discovery process and valve age group. The normalization is structured such that the average of the programmatic and nonprogrammatic values equals the relative failure rate for the age group as a whole

ORNL-DWG 93-7449

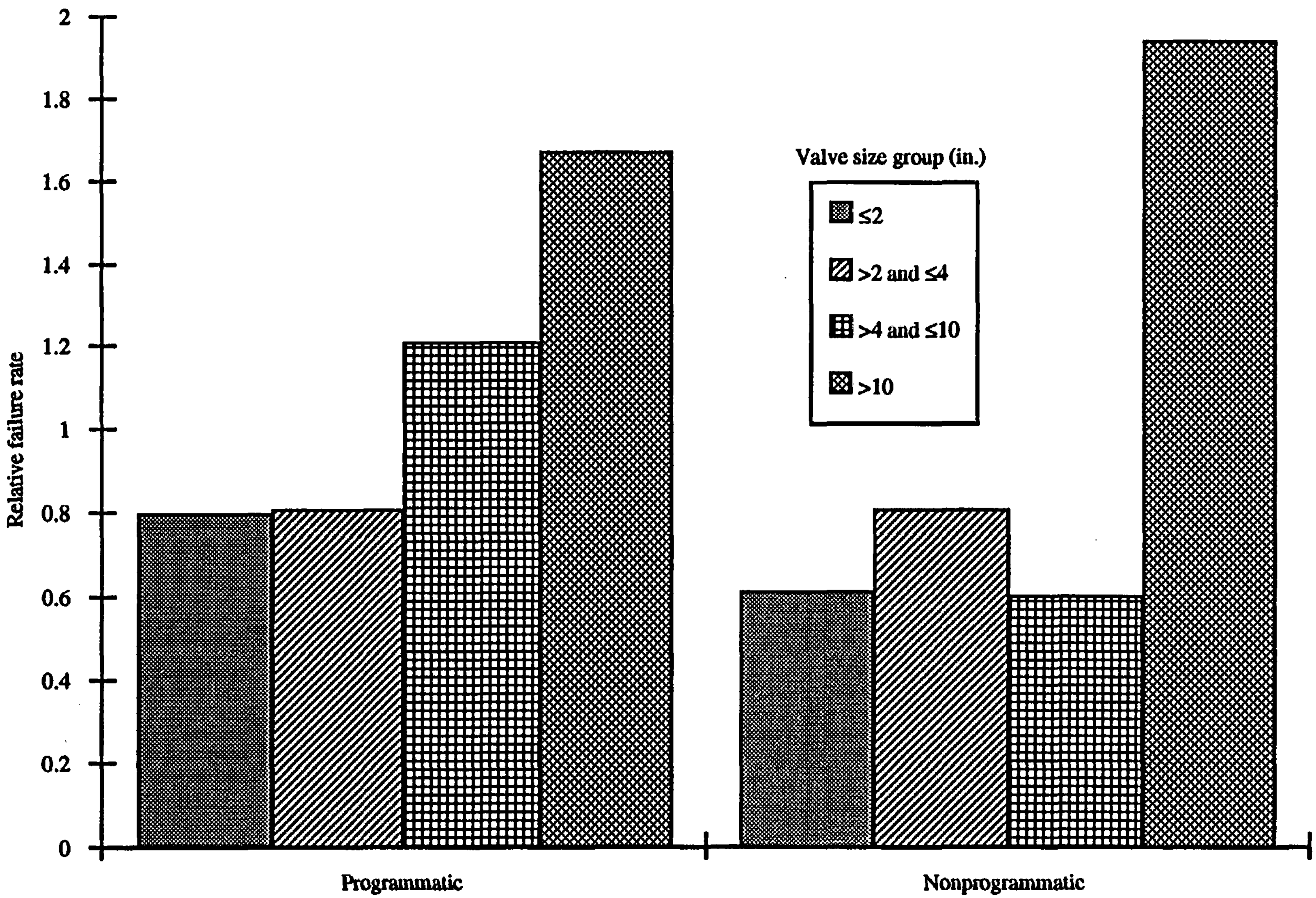


Figure A.11.3 Relative failure rate by discovery process and valve size group. The normalization is structured such that the average of the programmatic and nonprogrammatic values equals the relative failure rate for the size group as a whole

ORNL-DWG 93-7450

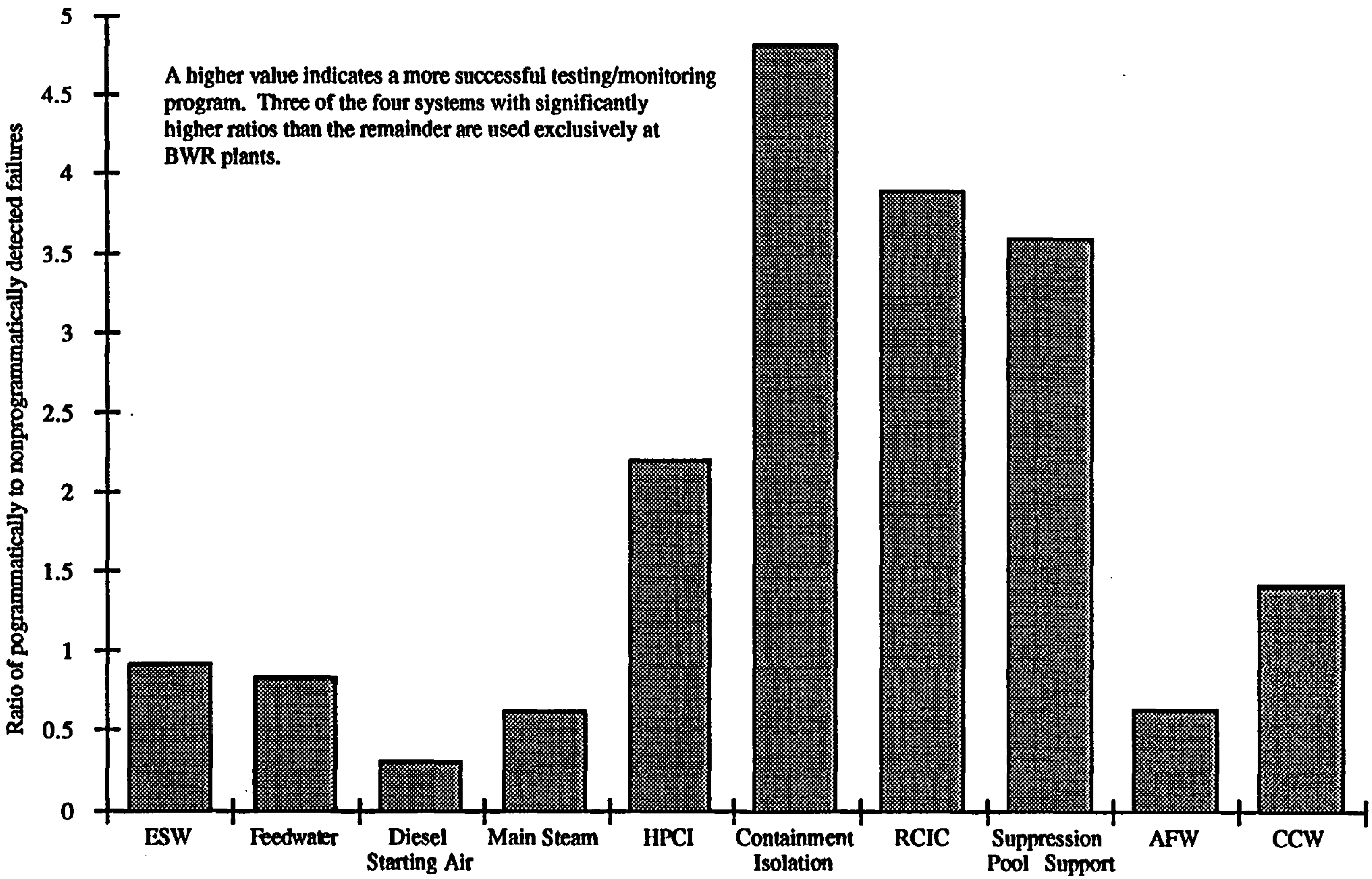


Figure A.11.4 Ratio of programmatically detected failures to nonprogrammatically detected failures for ten systems with the highest overall failure rate. A high value indicates that failures are more likely to have been detected programmatically

ORNL-DWG 93-7451

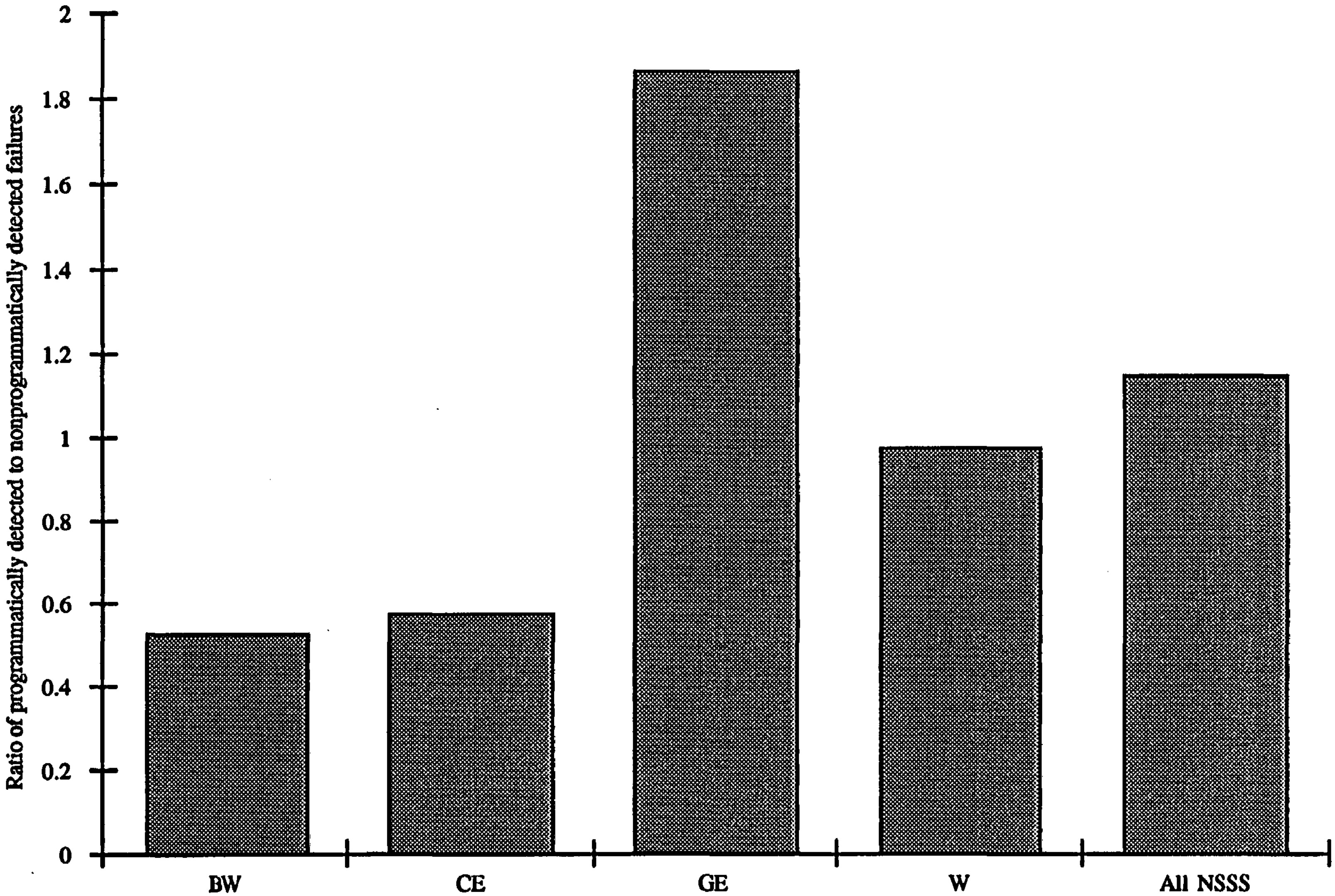


Figure A.11.5 Ratio of programmatically to nonprogrammatically detected failures by NSSS. GE plants have detected a significantly higher fraction of failures programmatically than have the PWR plants

ORNL-DWG 93-7452

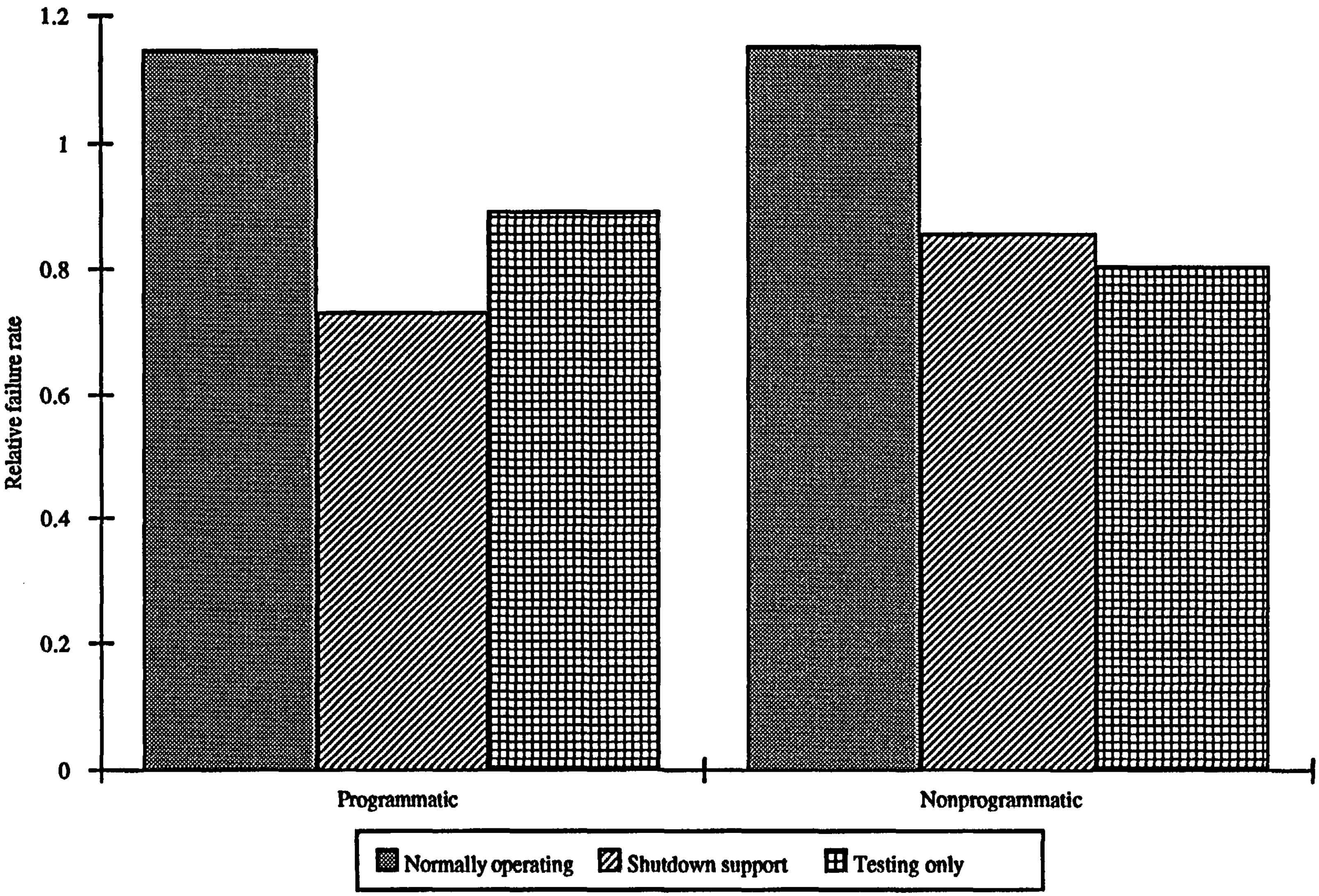


Figure A.11.6 Relative failure rate by general discovery process and system usage. The normalization is structured such that the service-weighted average of the failure rates for a given discovery process equals one

ORNL–DWG 93–7453

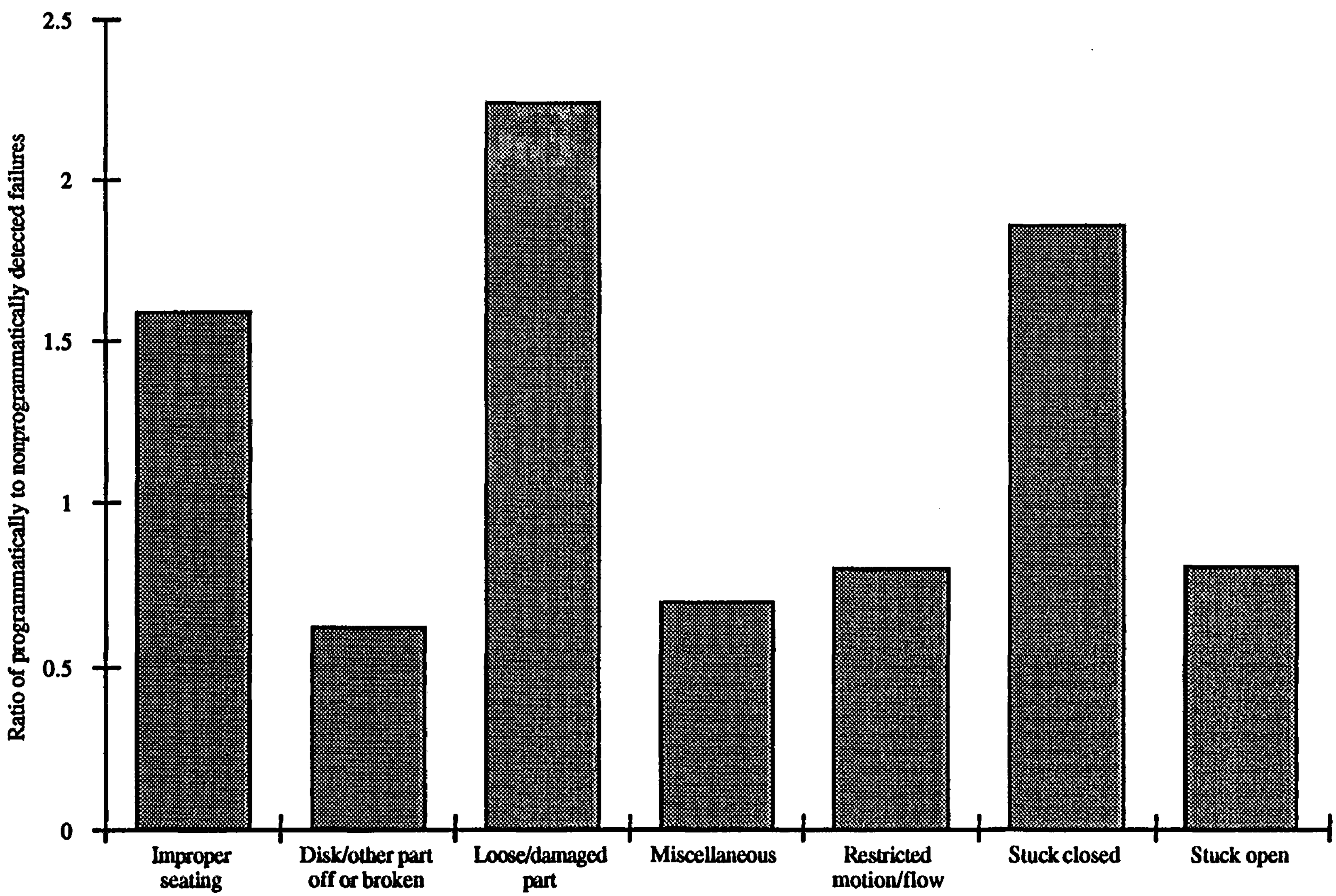


Figure A.11.7 Ratio of programmatically to nonprogrammatically detected failures by failure mode

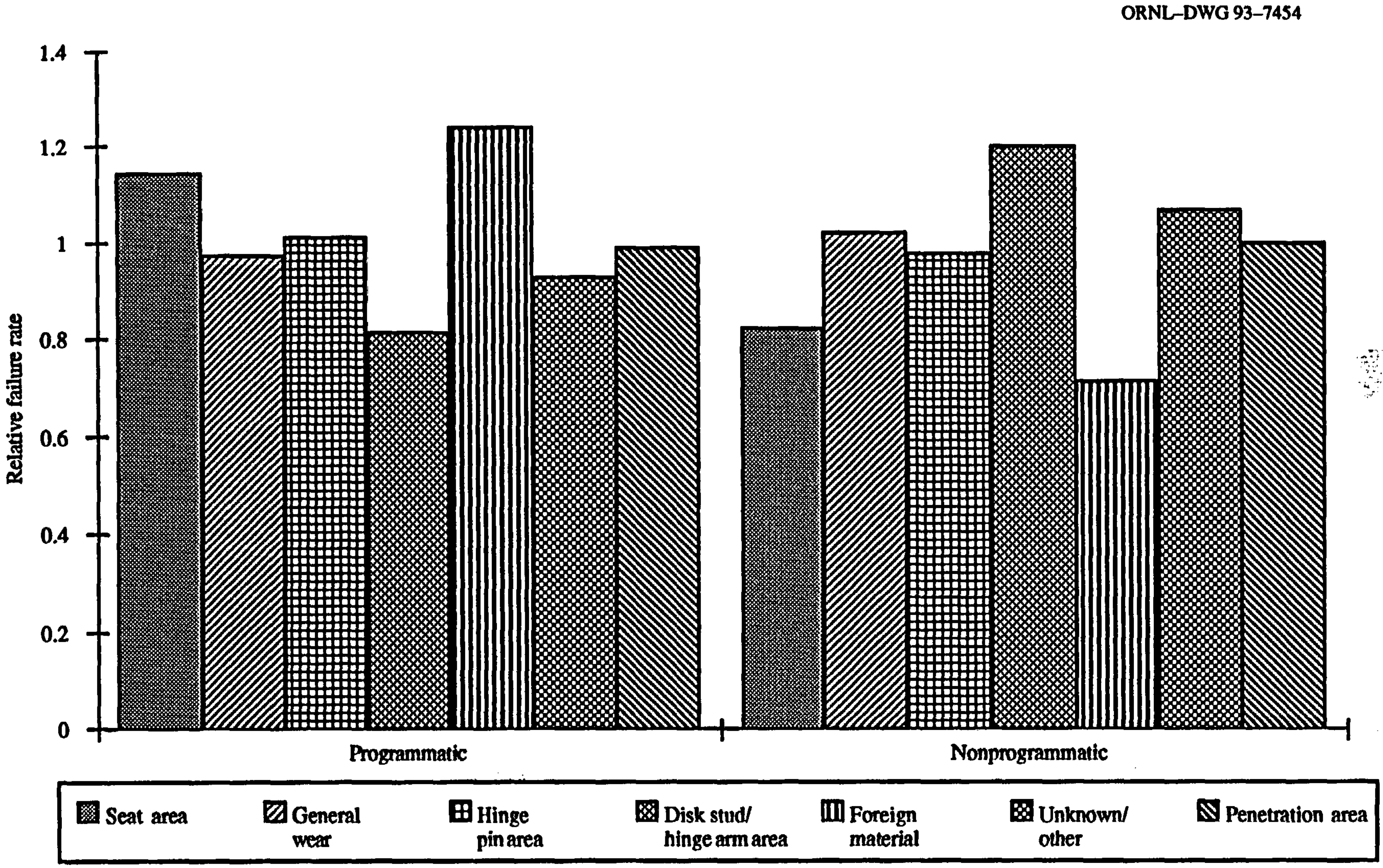


Figure A.11.8 Relative failure rate by affected area and discovery process. The values shown indicate how well failures in the designated areas were detected by the specified discovery process, relative to how all failures were discovered. For example, degradation from foreign material was about 25% more likely to be found programmatically than degradations in general, while degradation in the disk stud/hinge arm area was about 20% less likely to be detected programmatically than all degradations combined

ORNL–DWG 93–7455

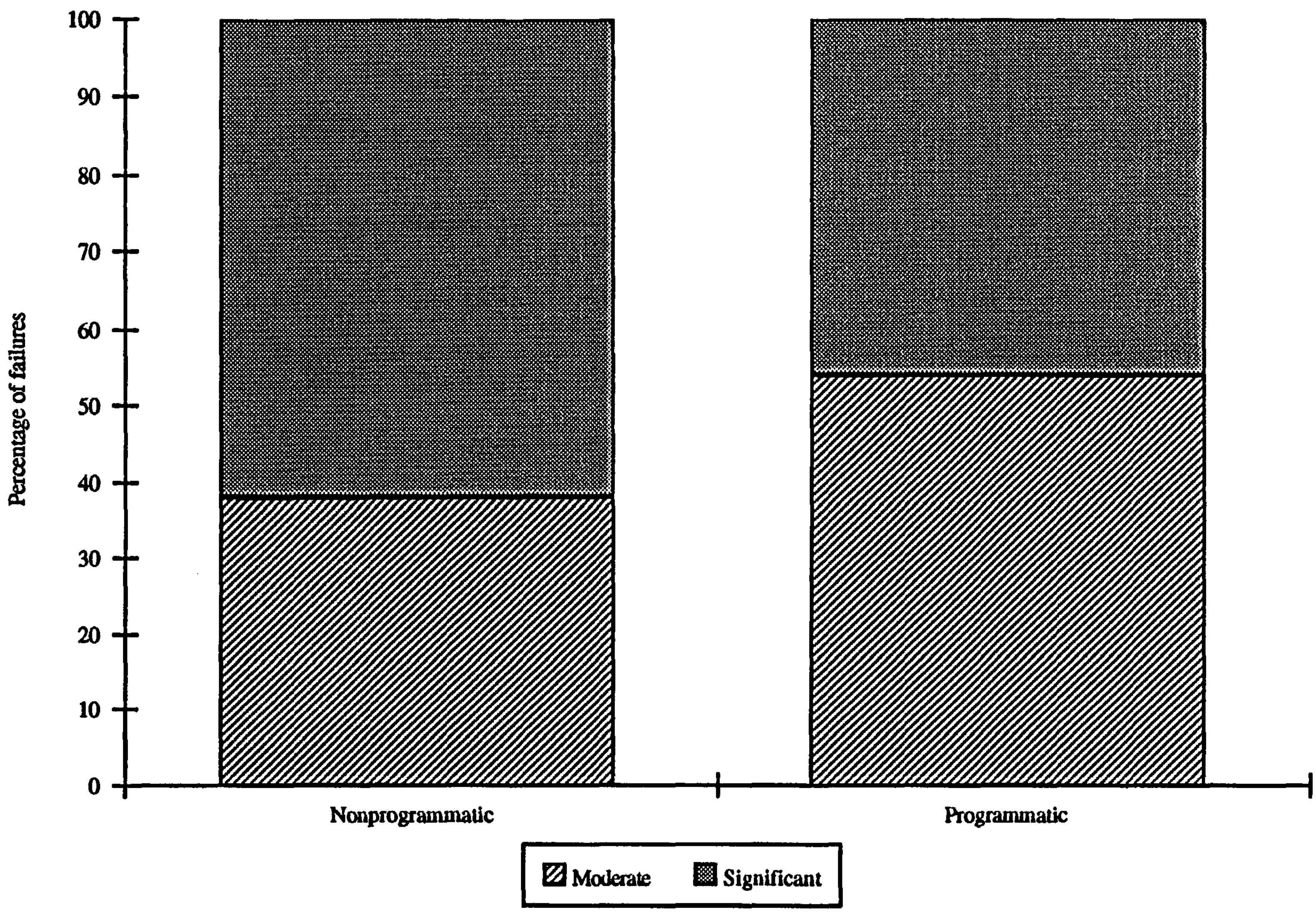


Figure A.11.9 Distribution of failures by extent of degradation and discovery process

ORNL-DWG 93-7456

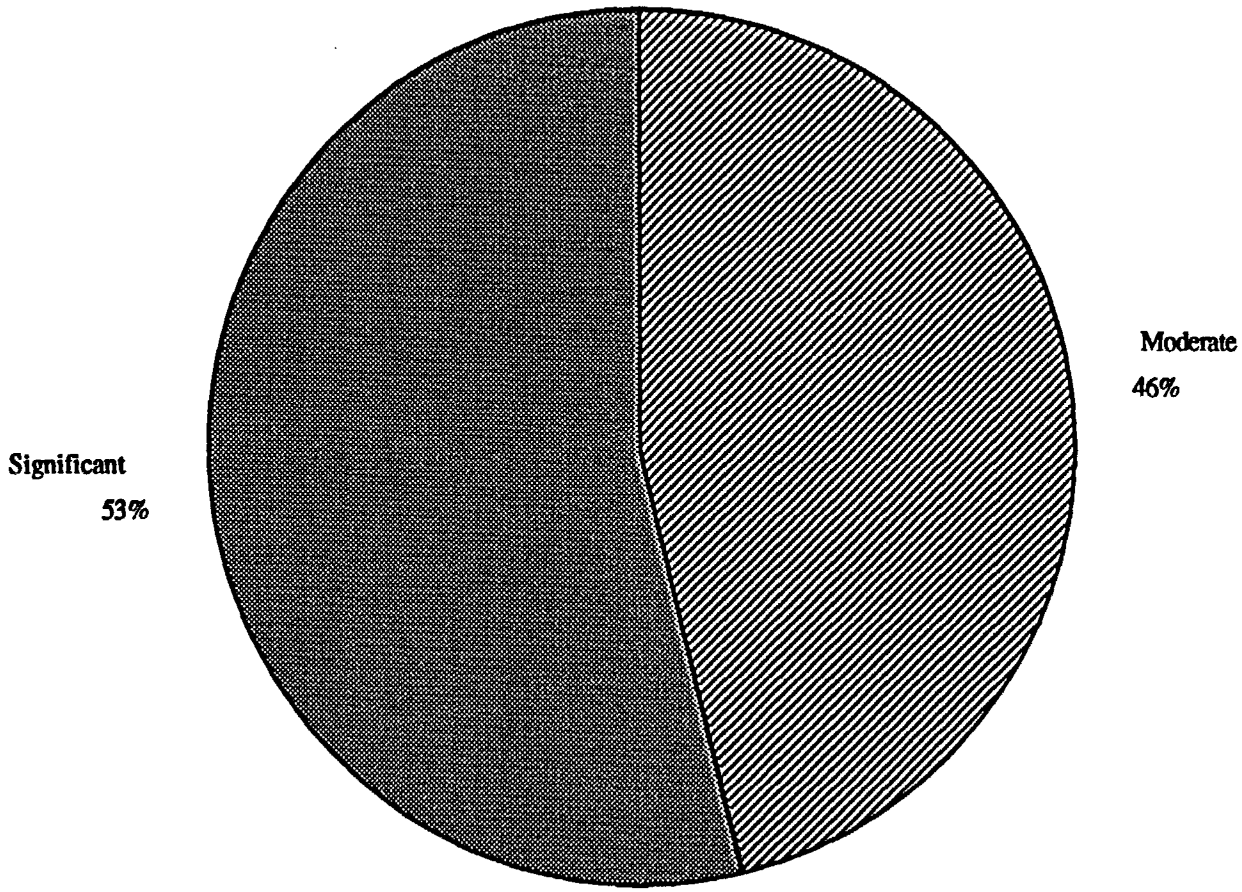


Figure A.12.1 Distribution of failures by extent of degradation

ORNL–DWG 93–7457

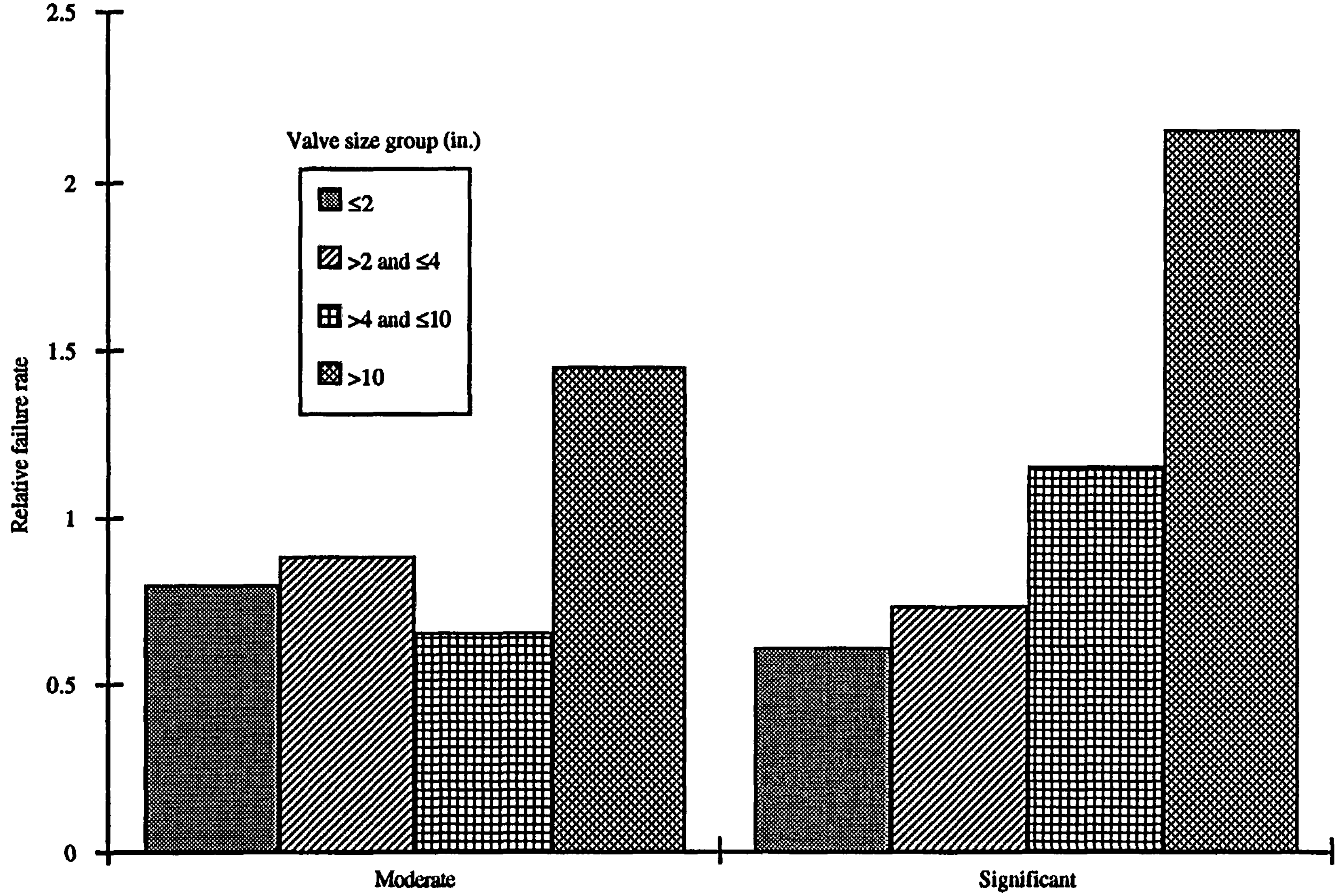


Figure A.12.2 Relative failure rate by extent of degradation and size group. The normalization is structured such that the average of the programmatic and nonprogrammatic values equals the relative failure rate for the size group as a whole

ORNL-DWG 93-7458

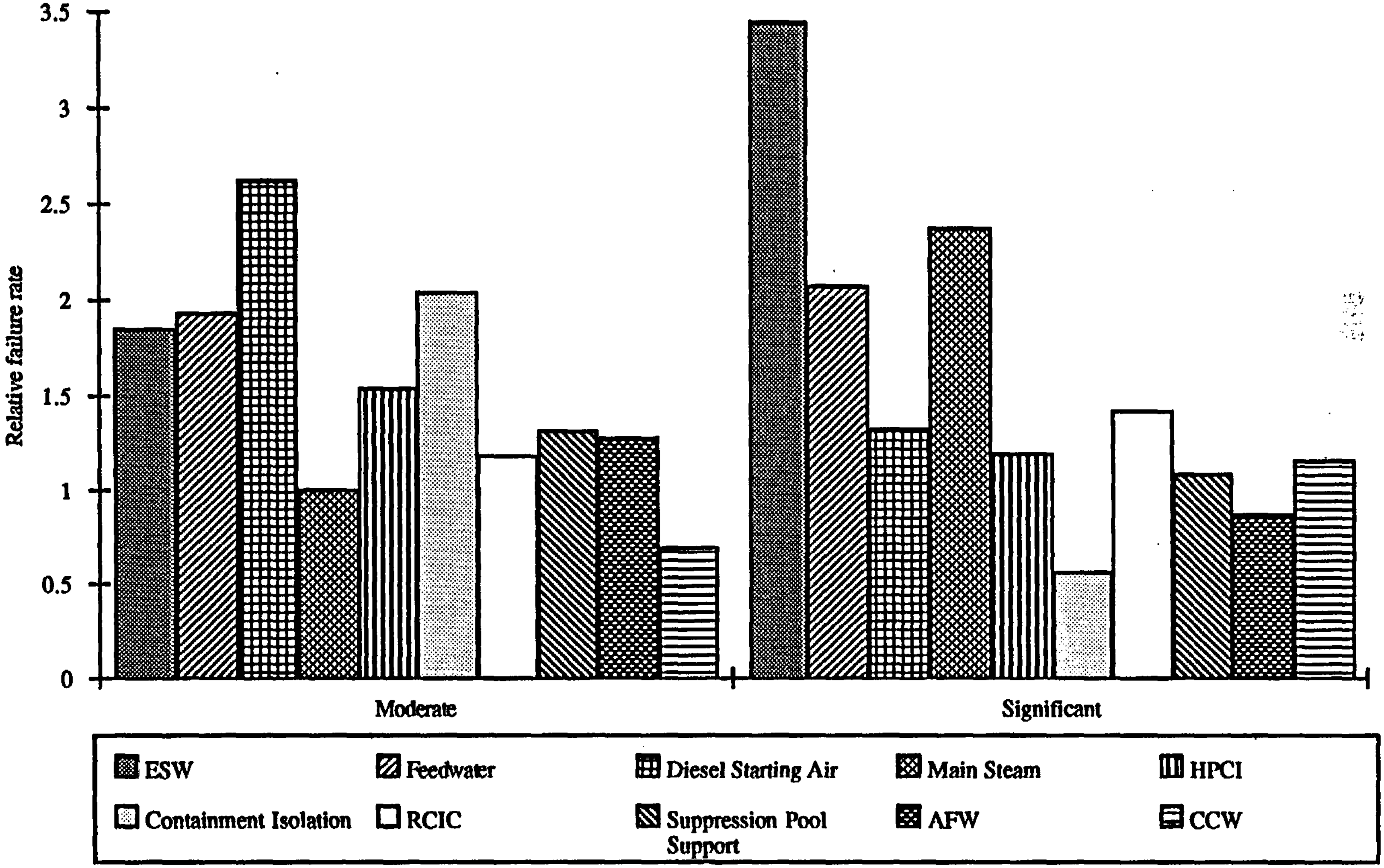


Figure A.12.3 Comparison of relative failure rates by extent of degradation and system for ten systems with the highest overall failure rate

ORNL-DWG 93-7459

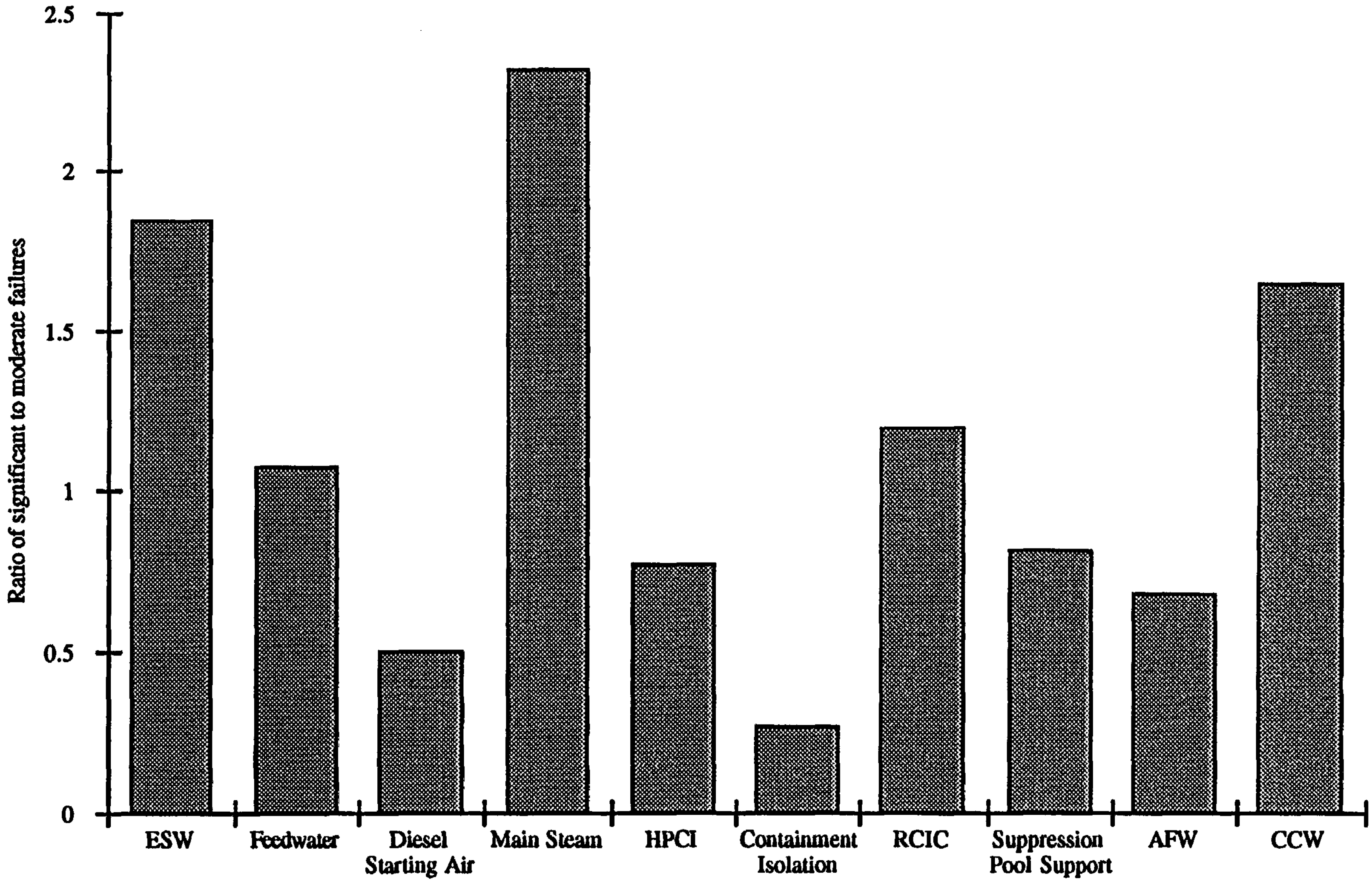


Figure A.12.4 Ratio of number of significant to moderate failures by system for ten systems with the highest overall failure rate

ORNL-DWG 93-7460

Figure A.12.5 Relative failure rate by extent of degradation for five manufacturers with the highest overall failure rate. The values shown reflect the rate of failures of the manufacturer's valves compared to all valves for each of the two categories

ORNL-DWG 93-7461

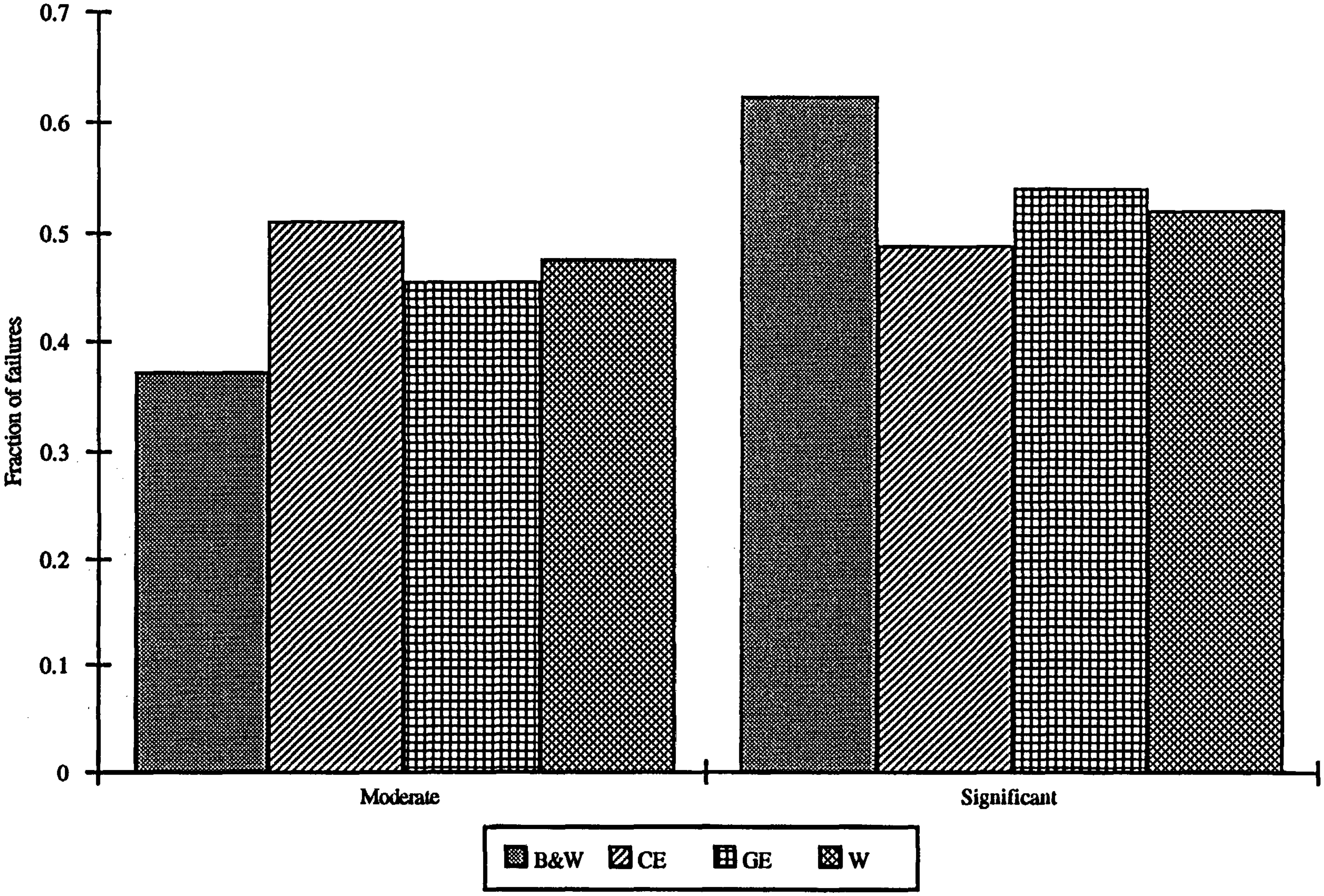


Figure A.12.6 Distribution of failures extent of degradation and NSSS

ORNL-DWG 93-7462

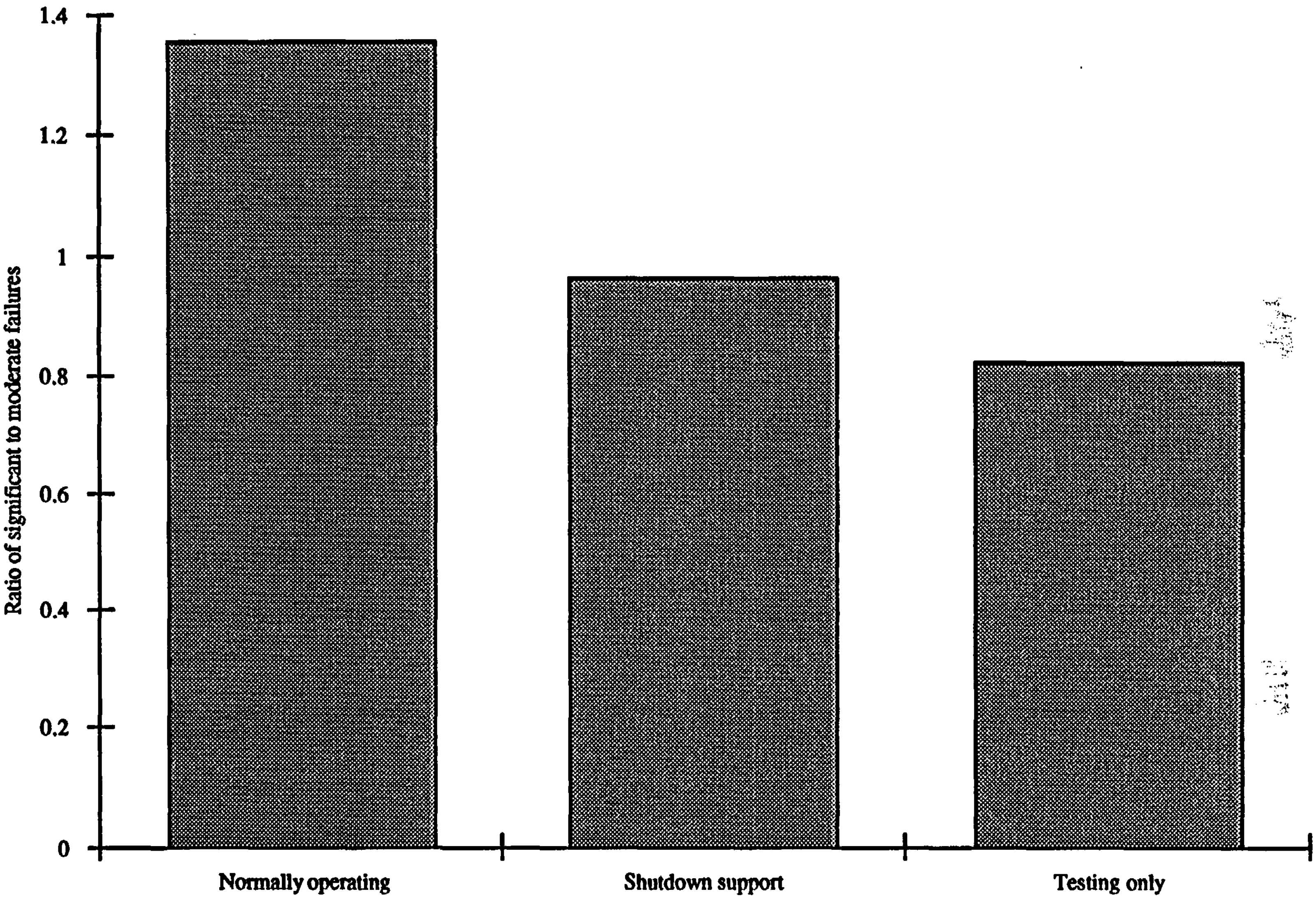


Figure A.12.7 Ratio of significant to moderate failures by system usage

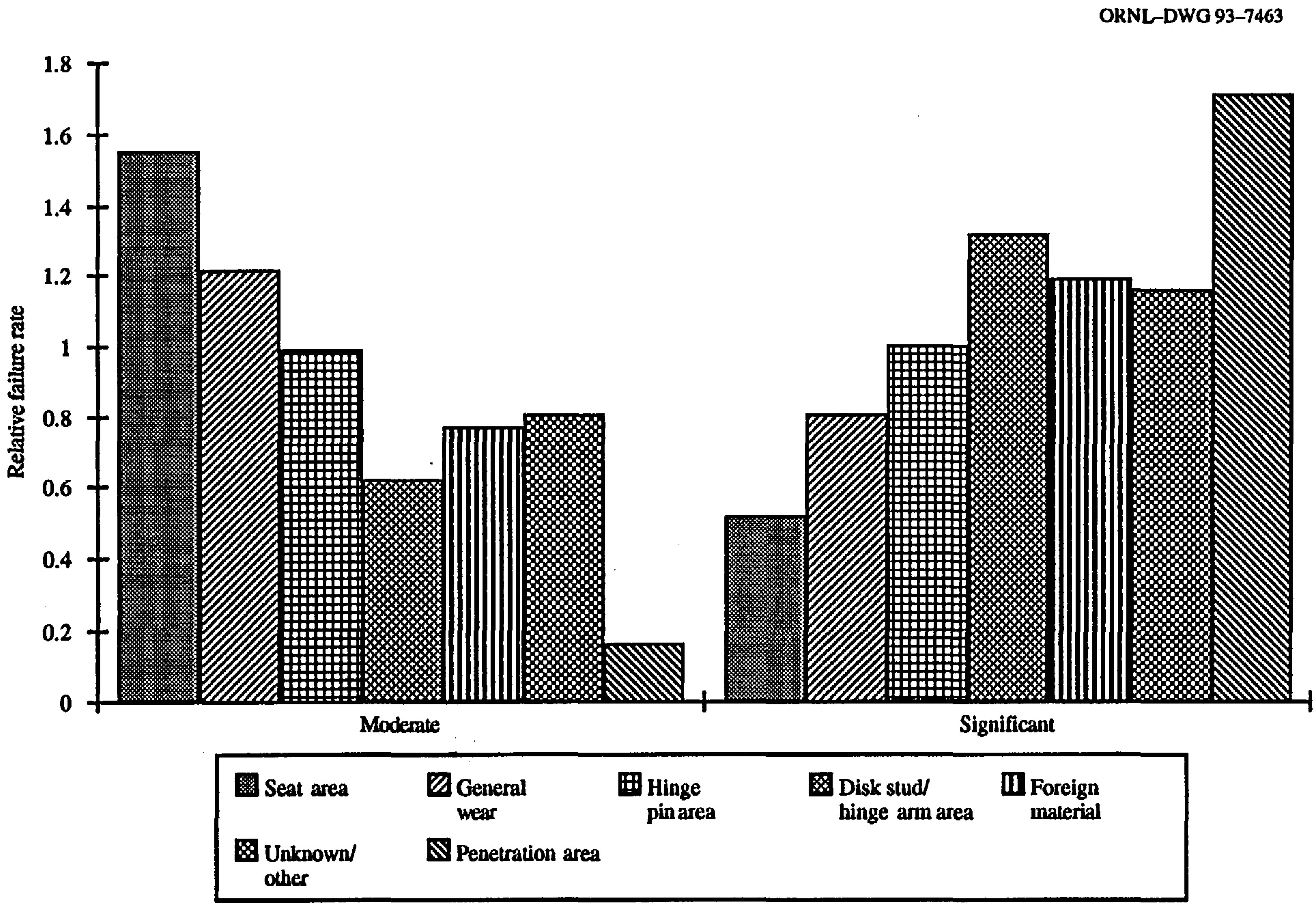


Figure A.12.8 Relative failure rate by failure area and extent of degradation. The values represent the relative population of failures of the specified extent of degradation within the designated failure areas, compared to the entire failure population. For example, failures involving the seat area were almost 60% more likely to be moderate in nature than the failure population as a whole

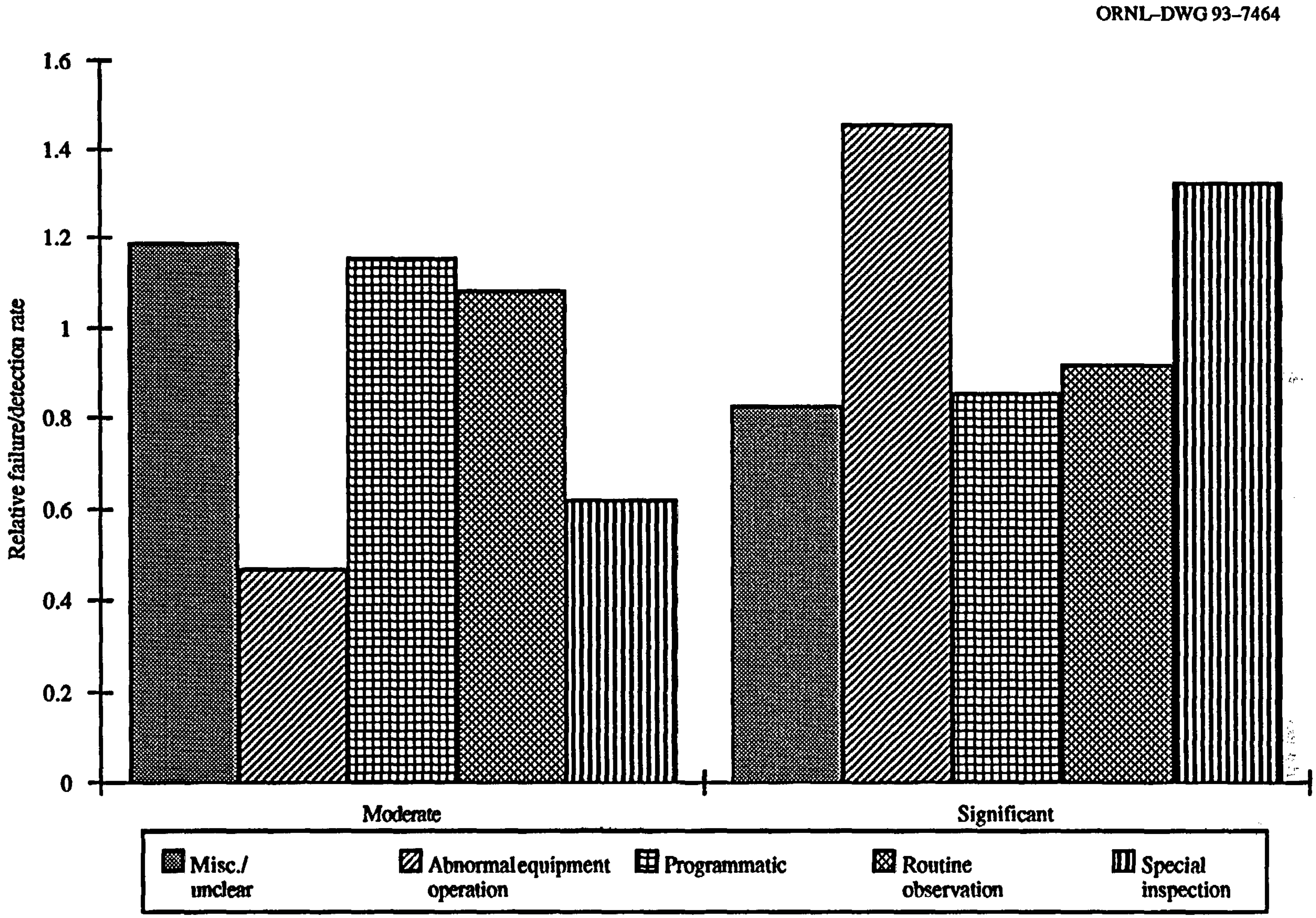


Figure A.12.9 Relative failure rate by extent of degradation and general detection method. The values represent the relative population of failures of the specified extent of degradation for the designated general methods of detection, compared to the distribution for the extent of degradation distribution for the entire failure population

ORNL–DWG 93–7465

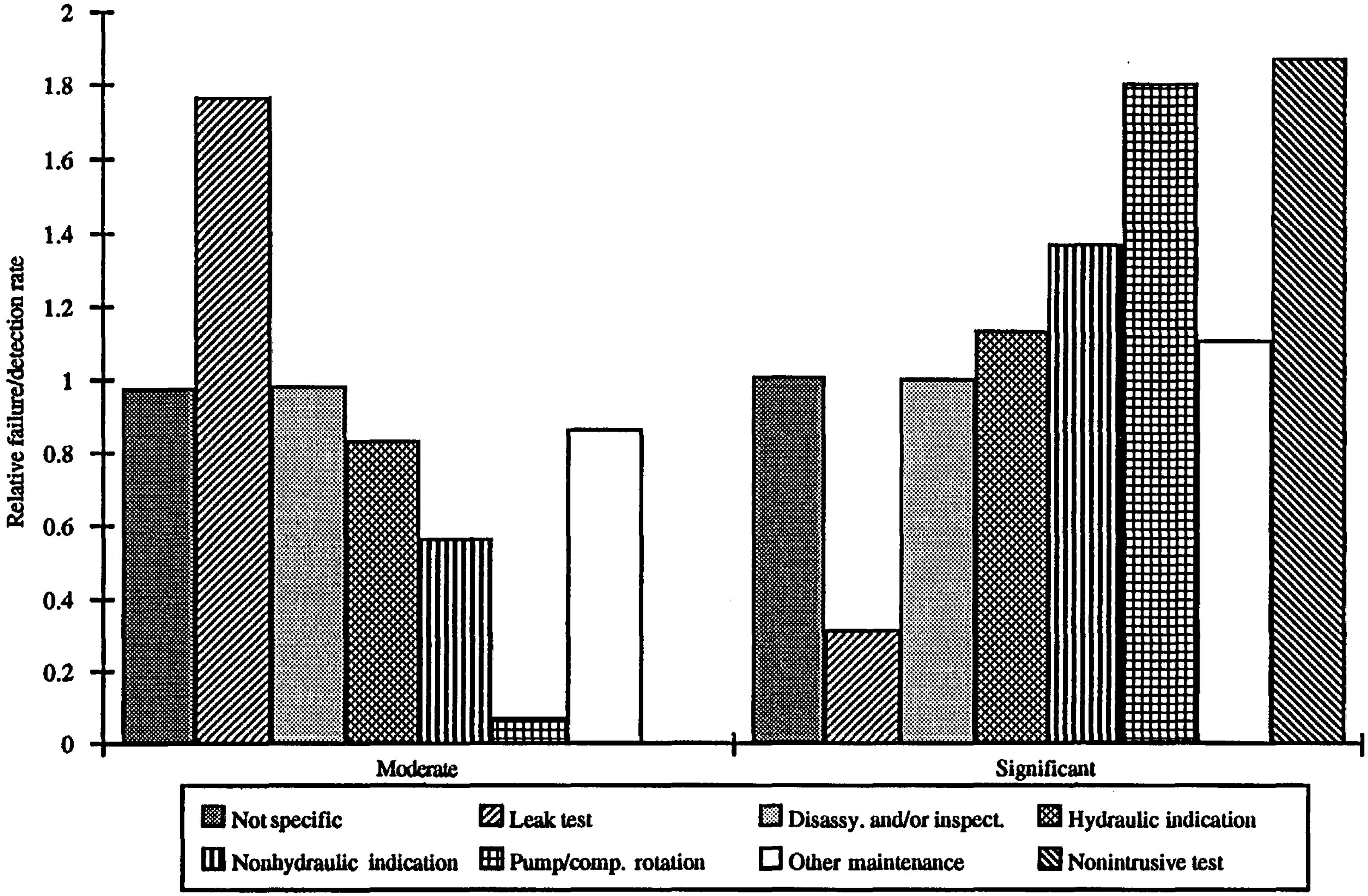


Figure A.12.10 Relative failure rate by extent of degradation and specific detection method. The values represent the relative population of failures of the specified extent of degradation for the designated specific methods of detection, compared to the distribution for the extent of degradation distribution for the entire failure population

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10. SUPPLEMENTARY NOTES

11. ABSTRACT *(200 words or less)*

Check valve operating problems in recent years have resulted in signifiant operating transients, increased cost and decreased system availability. As a result, additional attention has been given to check valves by utilities (resulting in the formation of the Nuclear Industry Check Valve Group), as well as the U.S. Nuclear Regulatory Commission and the American Society of Mechanical Engineers Operation and Maintenance Committee. All these organizations have the fundamental goal of ensuring reliable operation of check valves.

A key ingredient to an engineering-oriented reliability improvement effort is a thorough understanding of relevant historical experience. A detailed review of historical failure data, available through the Institute of Nuclear Power Operation's Nuclear Plant Reliability Data System, has been conducted. The focus of the review is on check valve failures that have involved significant degradation of the valve internal parts. A variety of parameters are considered, including size, age, system of service, method of failure discovery, the affected valve parts, attributed causes, and corrective actions.

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